**Samuel Fankhauser and Cameron Hepburn**

# Designing carbon markets, part I: carbon markets in time

## Article (Accepted version) (Refereed)

**Original citation:**
Fankhauser, Samuel and Hepburn, Cameron (2010) *Designing carbon markets, part I: carbon markets in time.* Energy Policy, 38 (8). pp. 4363-4370. ISSN 0301-4215

DOI: 10.1016/j.enpol.2010.03.064

# Designing Carbon Markets Part I:
# Carbon markets in time

Samuel Fankhauser[a] and Cameron Hepburn[b]

*23 March 2010*

## Abstract

This paper analyses the design of carbon markets in time (i.e., intertemporally). It is part of a twin set of papers that ask, starting from first principles, what an optimal global carbon market would look like by around 2030. Our focus is on firm-level cap-and-trade systems, although much of what we say would also apply to government-level trading and carbon offset schemes. We examine the "first principles" of temporal design that would help to maximise flexibility and to minimise costs, including banking and borrowing and other mechanisms to provide greater carbon price predictability and credibility over time.

***Keywords:*** carbon trading, environmental markets, banking and borrowing, EU ETS

---

***Acknowledgements:*** The paper is the result of a project undertaken for the UK Office on Climate Change in the context of the Lazarowicz Review on Global Carbon Trading. We are grateful to Alex Bowen, Simon Dietz, Graham Floater, Robin Smale, Andrew Wood and two anonymous referees for their comments and feedback, We would also like to acknowledge support by the Grantham Foundation for the Protection of the Environment, as well as the Centre for Climate Change Economics and Policy, which is funded by the UK's Economic and Social Research Council (ESRC) and by Munich Re. The usual disclaimers apply.

[a] Grantham Research Institute and Centre for Climate Change Economics and Policy, London School of Economics, Houghton St, London WC2A 2AE (UK); s.fankhauser@lse.ac.uk. (Corresponding author).

[b] Grantham Research Institute, London School of Economics, and Smith School for Enterprise and the Environment, Oxford University, 75 George Street, Oxford OX1 2BQ; cameron.hepburn@economics.ox.ac.uk .

# 1 Introduction

Carbon markets look set to grow rapidly over the coming years. Despite the onset of a global recession, carbon trading breached the $120 billion mark in 2008, up from $64 billion in 2007 (Capoor and Ambrosi, 2009). Within a decade trading volumes could reach $1 trillion, according to some market analysts, at which point the carbon market would start to rival current trading in established commodities like oil, gas or gold.

Given the likely rapid pace of growth in the carbon markets, this is a good moment in time to recap the economic case for carbon trading and review market design options. This paper is one of a twin set of papers addressing what a global carbon market could look like by around 2030, assessing design features relevant across time (this paper) and space (the companion paper). The companion paper (Fankhauser and Hepburn, 2010) examines market design features relevant to "where" flexibility, including key issues in linking national and regional carbon markets together to create a global carbon market. This paper examines design features relevant to the temporal dimension and "when" flexibility, including banking and borrowing and other mechanisms that can provide greater carbon price predictability and credibility over time.

Carbon markets look set to grow so quickly because of the recognition that any meaningful climate change policy must put a (long-term) price on carbon (Stern 2007), which would ideally provide private capital with a clear signal about the relative economics of low- vs high-carbon infrastructure investment. The need to price environmental externalities is a basic lesson from environmental economics (Baumol and Oates, 1988; Cropper and Oates, 1992). Added to this, the long time horizons and magnitude of capital investment required to address climate change imply spot carbon prices are not enough – politically credible long-term prices are required.

There are several ways of providing investors with the appropriate signal, including price-based instruments (e.g. carbon taxes), quantity-based instruments (e.g. carbon trading) and any number of hybrid instruments, such as price caps and floors (Pizer 2002, Jacobi and Ellerman, 2004, Philipbert 2009). Under idealised textbook assumptions taxes and trading are essentially equivalent, but in real world situations there are important differences due to imperfect information, transaction costs, external shocks, and political economy considerations (Hepburn, 2006, 2007).[1]

---

[1] The key reference on taxes versus permits remains Weitzman (1974). Hoel and Karp (2001) and

In considering the temporal aspects of carbon market design, it is helpful to remember that the choice between taxes and trading is not strict. There are ways to create hybrid instruments that blend price-based and quantity-based features, and hybrid instruments may be superior in several dimensions, including in reducing price volatility and increasing long-term credibility, discussed below.

The core benefit of hybrid systems is that they provide policy makers with greater control over the supply curve of emissions allowances. Like all markets, the market for emission reductions has a demand curve, determined by the marginal abatement costs of regulated entities, and a supply curve, which is determined by policy. Under a pure tax system, the supply of allowances is infinitely elastic. The market is effectively supplied with as many allowances as agents wish to buy at a fixed price (the tax rate). Under a pure allowance system, supply is completely inelastic as the amount of allowances is exogenously fixed. Hybrid systems allow policy makers to create a supply curve that is neither fully flat (a pure tax) nor fully vertical (pure cap-and-trade) but (stepwise) upward sloping.

The slope of the supply curve – that is, the ability to adjust supply over time – is linked to a critical design choice on the demand side: the degree to which compliance installations may spread emissions reductions over time. Such “when” flexibility is crucial to make carbon markets a cost-effective instrument for emission control. It allows market participants to minimise compliance costs over time. In principle, the more “when” flexibility is built into the demand side, the more cost-effective a market is likely to be. The rules on banking and borrowing of allowances within and between periods can also have strong effects on the liquidity and efficiency of the trading system.

“When” flexibility is maximised by full liberalisation of markets across time. However, there are factors that counsel against this. Most markets limit intertemporal arbitrage — the amount of banking and borrowing — in order to avoid time inconsistency problems, for instance. In this paper, we explore some of these challenges and suggest design features that may help to overcome them.

The structure of this paper is as follows. Section 2 sets out some “first principles” of design with respect to temporal issues that are woven throughout the rest of the paper. Our focus is on firm-level trading systems, although much of what we say would also apply to

---

Newell and Pizer (2003) have extended the Weitzman result to stock pollutants such as $CO_2$, where damage does not depend on the flow of emissions but on their accumulation in the atmosphere.

government-level trading (e.g., AAU trading under the Kyoto Protocol). In section 3, temporal design elements are considered in more detail, including banking and borrowing and other mechanisms to provide greater carbon price predictability and credibility over time. Section 4 concludes.

# 2 First principles of carbon market design – temporal issues

As our companion paper notes (Fankhauser and Hepburn 2010), the cost-effectiveness of climate policy is critical to its success or failure, because (i) our willingness to pay is limited and (ii) the costs of mitigation are substantial (see also Aldy and Barrett 2003). Costs are significantly reduced by allowing flexibility in when (and also where) emissions reductions occur. Abatement is generally cheaper if investment coincides with the natural renewal cycle of the capital stock. Retrofits or the premature replacement of equipment are expensive. Similarly, firms may need "when" flexibility to smoothen out fluctuations in the business cycle, manage their debt levels or take advantage of expected innovations. Furthermore, costs are reduced when carbon price volatility is lower, as this implies a lower risk (or reduced cost of hedging risk) created when carbon markets are relied on to provide an adequate return on investments in low-carbon infrastructure.

## 2.1 Price volatility

Price volatility is not necessarily a social problem; it is a natural feature of any well-functioning market and may reflect changes in underlying fundamentals (for example a change in oil prices).[2] As such, we distinguish between market-induced price volatility, which is not necessarily socially problematic, and volatility resulting from or exacerbated by regulatory design, which is undesirable and should be minimised through better market design. We now consider the impact of market design on price volatility.

To provide some formal structure, assume that the demand for permits $Q_d$ from firms is linear[3] and described by:

$$Q_d = \alpha_d - \beta_d P \tag{1}$$

where $P$ is the permit price, $\beta_d$ is the slope of the demand schedule and $\alpha_d$ is a demand parameter. The supply of permits is determined by policy. Assume that the supply of permits is linear, such that policy determines the relevant slope of the supply schedule:

$$Q_s = \alpha_s + \beta_s P \tag{2}$$

---

[2] In some markets, in particular asset markets, price volatility may also arises from the animal spirits of investors (Smith et al., 1988).

[3] The Appendix provides a more general analysis with isoelastic demand and supply curves.

where $\beta_s$ is the slope of the supply schedule and $\alpha_s$ is a parameter. When supply is infinitely elastic, $\beta_s = \infty$, policy is effectively a pure carbon tax. When supply is inelastic, $\beta_s = 0$, policy is a pure carbon trading scheme. Hybrid schemes allow for intermediate values.

The clearing price for permits is this:

$$P = \left(\frac{\alpha_d - \alpha_s}{\beta_d + \beta_s}\right) \tag{3}$$

Consider price volatility created by shocks to demand for permits (e.g. changes in relative coal and gas prices, or the introduction of new abatement technologies) rather than from policy shocks. Assume that demand is uncertain and distributed normally such that:

$$\alpha_d \sim N(\bar{\alpha}_d, \sigma_\alpha^2) \tag{4}$$

Then one simple indication of price volatility is the variance of price, given by:

$$var\,(P) = \left(\frac{1}{\beta_d + \beta_s}\right)^2 \sigma_\alpha^2 \tag{5}$$

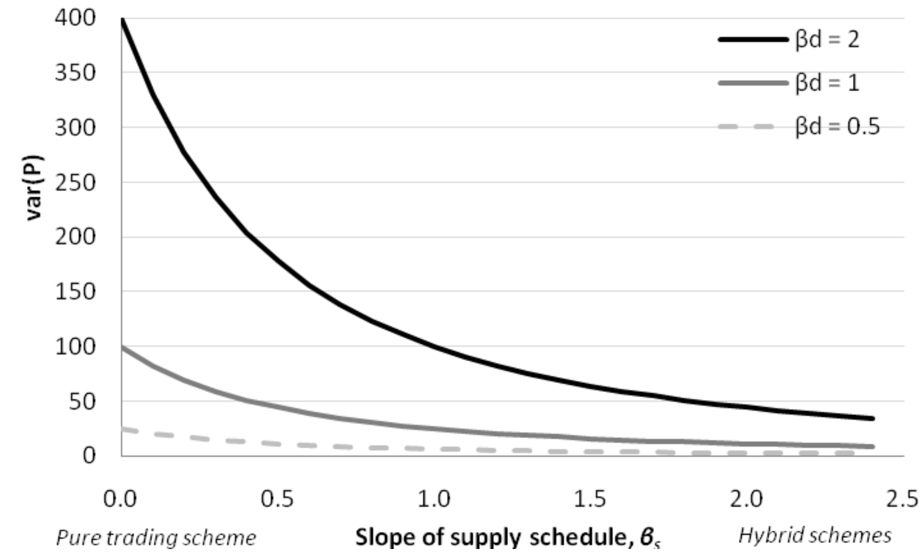
Given this variance in price, the policy maker can adopt different design features to impact the slope of the supply curve, $\beta_s$, to minimise price volatility. The impact of $\beta_s$ on price variance is given by:

$$\frac{\partial var\,(P)}{\partial \beta_s} = -2\left(\frac{1}{\beta_d + \beta_s}\right)^3 \sigma_\alpha^2 < 0 \tag{6}$$

In other words, increasing the slope of the supply curve $\beta_s$, for instance by moving from a carbon trading scheme, with a fixed cap and inelastic supply ($\beta_s = 0$), to carbon taxes where supply is infinitely elastic ($\beta_s \rightarrow \infty$), or a hybrid scheme, will reduce price volatility. The key point is that the policy maker has control over the shape of the supply curve. She can trade off price volatility and certainty of emission limits (Metcalf 2009).

Figure 1 shows carbon price volatility as a function of the slope of the supply schedule for three different values of the slope of the demand schedule. Price volatility falls as the slope of the supply schedule is increased (i.e. as policy moves from trading to hybrids and taxes). Unsurprisingly, price volatility also falls as the demand schedule becomes flatter.

**Figure 1: Price volatility as a function of the slope of the supply schedule**




*Note: var(P) is normalised against the variance of an inelastic supply schedule when the slope of demand schedule is unity (100).*

## 2.2 When flexibility and long-term credibility

The theoretical insights on "when" flexibility suggest an efficient market has long-term commitment periods, or "phases", in which firms can freely bank or borrow their emissions allowances. The length of the commitment period is important because (i) unlimited banking and some form of borrowing are generally allowed within commitment periods;[4] and (ii) there is normally clarity about the emissions cap for any given commitment period, but uncertainty about emissions cap for future commitment periods.[5] An alternative to long commitment periods would be to provide full scope for banking and borrowing of allowances between commitment periods to allow firms to optimise the time at which they reduce emissions.

A market with long-term commitment periods and/or banking and borrowing not only increases "when" flexibility, it also increases liquidity by allowing firms to trade across time

[4] For instance, the EU ETS Phase 2 allows unlimited banking between periods: EUAs of vintage 2008 may be used for compliance in 2011. Limited borrowing is allowed in that allowances for 2009 may be used for compliance for the 2008 period.

[5] The EU ETS aims to address this by extending the annual emission reduction target for phase III (1.74% p.a.) beyond the end of phase III. However, the target is of course subject to future review.

periods. Furthermore, long-term price signals would be expected to support stronger innovation that creates new abatement opportunities. This has been a source of much recent discussion, with many observers questioning the strength of the dynamic signal of the EU ETS.

In reality, there are political and economic constraints preventing a very long-term carbon market with full temporal flexibility from emerging. The main constraint is on the extent to which firms can borrow, rather than bank, allowances between commitment periods. This is because:

(i) the government may not be well-equipped to assess the credit worthiness and solvency of firms who borrow allowances, who thereby become debtors. Moreover, firms which are least solvent are likely to want to borrow more than firms which are most solvent (a form of *adverse selection*);

(ii) borrowing enables firms to delay action if they assume that targets will prove too onerous and will subsequently be softened (a *time inconsistency* issue);

(iii) firms with borrowed allowances have an active interest to lobby for weaker targets, or even for scrapping emissions trading altogether, so that their debts are cancelled (a form of *moral hazard*).

(iv) the political desire to (be seen to) act early, and potential benefits of early action, also imply that politicians may prefer to place constraints on borrowing.

These concerns about borrowing imply that most trading systems do not allow borrowing between commitment periods, and often even limit borrowing within commitment periods.[6] In contrast, banking does not create such difficulties: firms with banked allowances have a vested interest in higher prices and the continuation of the system, to maximise the value of their allowance assets. Banking can also prevent a price collapse between commitment periods. For these reasons, most emissions trading systems have allowed banking in some form. A notable exception is phase I of the EU ETS, where banking was not allowed and the price duly collapsed at the end of the period.

When there are limits on borrowing between periods, but some borrowing allowed within periods, it follows that the *length* of the commitment period is relevant to "when" flexibility and to market efficiency. Period length is also relevant when investments to reduce emissions require many years for investors to recover their costs (including the cost of capital). If commitment periods are short, investors have to guess the emissions caps set by future governments, and attempt to anticipate changes in the underlying structure of the

[6] Individual firms may, of course, borrow allowances from other regulated firms on a bilateral or exchange-cleared basis. But such trades do not threaten the integrity of the system

carbon trading framework. These uncertainties significantly increase risk and reduce the likelihood of low-carbon investments being made (Helm et al. 2003). In addition to providing better incentives for innovation, longer commitment periods are supported by the most recent science, which suggests that cumulative emission targets to 2050 provides a more robust approach to limiting the probability of temperature increases above 2$^{o}$C (Allen et al., 2009; Meinshausen et al., 2009). Setting overall long-term targets has the additional benefit of leaving the optimal time path of emission reductions to the market, without policy makers needing to second guess the dynamically efficient path.[7]

While short commitment periods create problems, they also have benefits.[8] Short periods leave governments the flexibility to set future caps according to changes in science or in the availability of new abatement technologies. Short periods may also be more credible, particularly if they coincide with the electoral cycle. This has value. However, if governments wish to retain the benefits of short commitment periods, other mechanisms are likely to be needed to address the shortcomings[9] and to provide the private sector with appropriate long-term incentives for low-carbon investment.[10]

We now consider, in more detail, the design features that can overcome some of these limitations to "when flexibility", while seeking also to maintain "where" flexibility as much as possible.

[7] The market will not necessarily provide price signals far into the future. Price formation is hampered by increasing uncertainty as forecasts extend further into the future. However, fixing long-term targets would nevertheless remove one key aspect of uncertainty.

[8] A discussion is provided by Hepburn (2006), who notes that the flexibility also brings additional costs, one of which is the "hold up" problem created by the fact that the government arguably has an incentive to adjust policy to address other objectives *ex post* firms have sunk resources into irreversible low-carbon investment.

[9] These include potential negative impacts of shorter periods on incentives to invest in longer-term low-carbon research and innovation.

[10] Examples include long-term carbon contracts (Helm and Hepburn, 2008) or issuing put options (Ismer and Neuhoff, 2009).

# 3 Temporal design options

We start from the theoretical ideal of long commitment periods (section 3.1), before noting that a system with banking and borrowing between periods (section 3.2) can deliver largely the same benefits. In the absence of banking and borrowing, other mechanisms may be considered to smooth prices and provide clearer longer-term signals which may enhance "when" flexibility. These include setting reserve prices in allowance auctions to ensure prices do not fall too low (section 3.3), creating an "allowance reserve" to be deployed if prices rise too high (section 3.4), or deploying more rigid price ceilings and floors (section 3.5). The advantages and disadvantages of each design feature are considered.

## 3.1 Commitment period length

Section 2 noted that banking and borrowing are often permitted (at least to some extent) within but not necessarily between commitment periods.[11] For instance, in the EU ETS, there is full banking within a commitment period, because EUAs are valid throughout the commitment period, in addition to banking between periods (Article 13). In contrast, there is only limited *de facto* borrowing within a commitment period, and no borrowing at all between commitment periods. The *de facto* borrowing is made possible because operators are allocated their allowances for each year in February, but need to surrender units for the previous year on 30 April, so they can effectively borrow one year ahead. Furthermore, as increasingly higher proportions of allowances are auctioned, even this limited *de facto* borrowing within periods will be effectively phased out.

When there are limits on banking or borrowing between periods, longer commitment periods allow greater temporal flexibility, smoothing prices, reducing costs and increasing liquidity. For instance, a single 10-year commitment period is equivalent to two 5-year commitment periods where:

— banking and borrowing between the two periods is allowed; and
— the second period cap is pre-announced and is credible.

[11] It is important to draw the distinction between the "commitment period" (for instance 2008-2012 in the current Phase II) and the "compliance period", which is annually under the EU ETS where firms have to submit the appropriate number of EUAs (or other recognised unit) to cover their emissions for the previous year on 30 April. Our discussion focuses on the length of commitment periods rather than compliance periods.

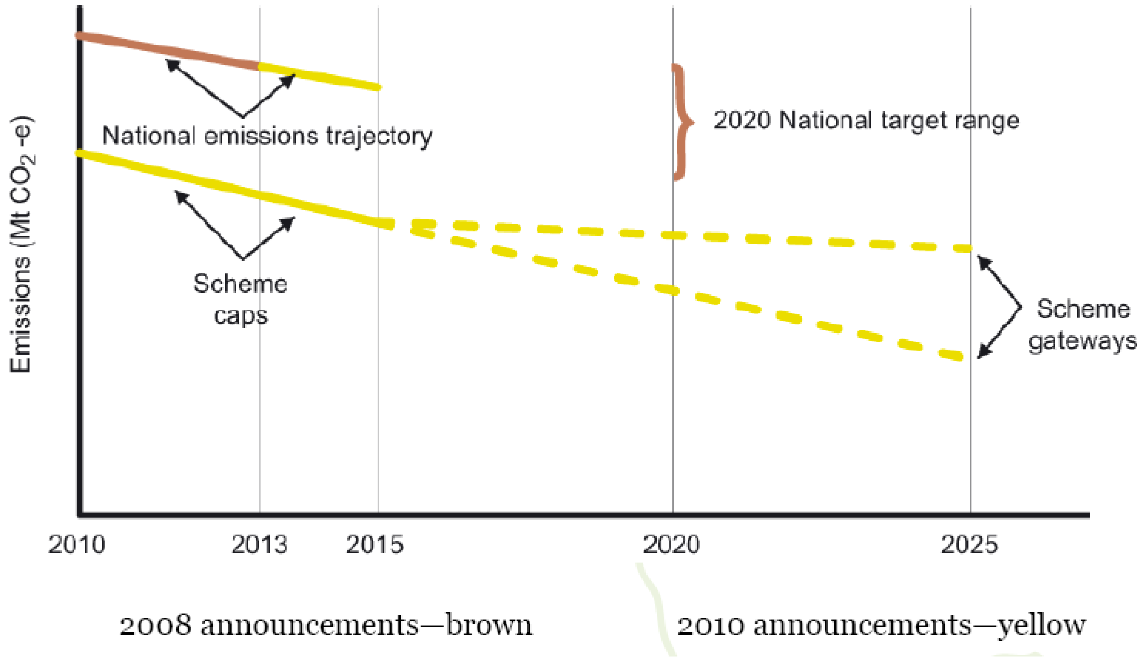
Longer periods not only maximise "when" flexibility, they also reduce price volatility, and provide the private sector with longer-term price signals which, if credible, should spur innovation and investment. However, longer periods reduce policymakers' flexibility to adjust targets in response to changing science or new abatement technologies. Different trading systems have struck the balance between these objectives in noticeably different ways.

For instance, in the EU ETS, Phase I was a three year commitment period, with no banking or borrowing between Phase I and II. While the scheme did appear to stimulate emission reductions (Ellerman and Buchner, 2007), three years was short, even for a "learning phase". The Phase II commitment period is five years which is still arguably too short, although as noted banking to Phase III is permitted. Phase III has an eight years period, which appears to be better matched with the relevant investment cycle, although firms are still faced with considerable uncertainty at the end of the 8-year Phase III period in 2020, unless Phase IV is negotiated well in advance. This is the case even though the Commission has stated that the annual reduction in the cap during Phase III would be extended into Phase IV.

In contrast, the Waxman-Markey draft bill sets out long-term reduction targets through to 2050, providing greater clarity to investors on the time profile of abatement. Allowances are to be reduced each year so that aggregate emissions under the system are reduced by 3% below 2005 levels in 2012, 20% in 2020, 42% in 2030, and 83% in 2050 (Section 702). Alongside these long-term targets are unlimited banking and limited effective borrowing, discussed further in section 4.2 below, generating long-term signals with significant "when" flexibility for firms. However, the bill also provides some flexibility for government: the US National Academy of Sciences is required to submit a report every four years on the state of climate science, the "technological feasibility of achieving additional reductions in greenhouse gas emissions", and an analysis of worldwide efforts (Section 705) and thus make recommendations about making additional reductions.

The proposed Australian Carbon Pollution Reduction Scheme ("CPRS") provides a different model of how to address this balance between long-term price signaling and policy flexibility (Government of Australia, 2008; Jotzo and Betz 2009). The CPRS provides firms with a certain emissions cap for five years into the future, with a "gateway", or range of potential emissions caps covering the next ten years, as shown in Figure 2. Each year, the five-year cap and the ten-year gateway are updated, so that at any given point in time the private sector has 15 years of an indicative range of cuts and 5 years of a defined cap. The use of rolling commitment period that is updated annually avoids the sharp uncertainty between periods from which the EU ETS suffers.

**Figure 2 Caps and gateways in the Australian CPRS**




Source: Government of Australia (2008)

## 3.2 Banking and borrowing

The end of a commitment period provides the real risk of a price crash or spike if participants are unable to bank and borrow allowances respectively. Without banking, if the market is slightly over-allocated (as in EU ETS Phase I), then the marginal allowance is worthless and the price will collapse to zero (as it did). Without borrowing, if the market is slightly under-allocated, then the value of the marginal allowance could spike to the penalty plus expected price in the next phase (unless there are quick-to-implement abatement options that can be deployed fast once the under-allocation becomes known).[12]

Banking and borrowing may also increase the scope for the government to softly and credibly manage carbon prices so that they remain within a particular window. Newell et al. (2005) note that in a multi-period system with banking and borrowing, prices could be managed by agreeing that the stringency of targets in the next period automatically depend upon the revealed price in the current period.

There are several even more significant advantages to banking, and very few drawbacks, which is why banking is now a widely adopted feature of emissions trading systems. As

[12] Another way of avoiding end-of-period price fluctuations is by opening the market to carbon offsets.

noted, banking would have prevented the price crash observed in Phase I of the EU ETS, and indeed it is probably also playing a role in supporting prices in the current Phase II. Banking has several further advantages, namely that it:

— effectively increases the depth and liquidity of the market, reducing price volatility by making current prices a function of a longer time span of activity, rather than being entirely determined by events today;
— creates an incentive for firms to take early action to reduce emissions;
— creates a private sector group with a vested interest in the success of the system, including an incentive to ensure rigorous monitoring and enforcement, as well as tight future targets, to protect and maximise the value of their carbon assets.

Borrowing also enhances “when” flexibility and would also be likely to reduce price volatility. However, in contrast to banking, unlimited borrowing has some significant drawbacks, noted in section 2, related to adverse selection, moral hazard, time inconsistency and the credit worthiness of borrowing firms.

For these reasons, borrowing is currently limited, and is likely to remain so. In the EU ETS, borrowing is restricted to a *de facto* interest free loan of one year’s allowances (noted above), which is effectively being phased out as auctioning is brought in. After 2012, the EU ETS has retained the option of moving forward the auctioning of allowances from future years if market prices rise too high, providing the potential for a further form of borrowing within a given commitment period.

Similarly, in the Waxman-Markey draft bill, rolling two-year compliance periods effectively allow operators to borrow one year ahead at a zero interest rate. However, the Waxman-Markey draft bill goes further than the EU ETS, and allowances from two to five years into the future can be borrowed (at an unspecified positive interest rate), up to a limit of 15% of the total obligation.

Differences in banking and borrowing provisions do not preclude links between systems, but they may pose important obstacles. Systems with borrowing have risks to their environmental effectiveness if an operator borrows allowances and goes bankrupt before they are repaid. If this were a significant concern, one solution proposed is to limit purchases to allowances found *ex post* to be surplus to emissions in a compliance period from firms who have not borrowed (Haites and Mullins, 2001). Similarly, linking of one system with banking to another system with banking effectively creates a banking option for the system without banking.

## 3.3 Auction reserve prices

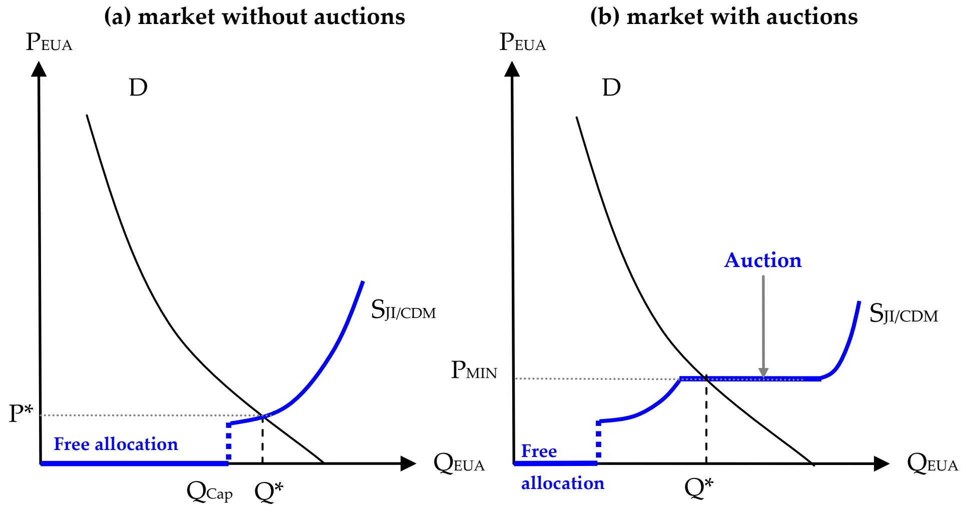
In the absence of long commitment periods and banking or borrowing, governments may seek other mechanisms to minimise price volatility and to increase the dynamic efficiency of the carbon market. Governments may wish to provide support to carbon prices to ensure that firms continue to have an incentive to reduce emissions (this section), or may want to ensure prices do not rise too high (section 3.4), or establish more rigid price ceilings or floors (section 3.5).

As the proportion of allowances allocated by auction increases, one “soft” approach to managing the risk of low carbon prices[13] is to set a reserve (or minimum) price for the periodic auction of the allowances, such that no allowances would be sold onto the market if the reserve price was not reached (Hepburn et al, 2006). Auctions would need to occur at various points over the commitment period, as indeed is planned, rather than auctioning all of the allowances upfront. Firms would not buy allowances at the auction if market prices were below the reserve price, so the reserve price would serve to reduce the supply of allowances onto the market when prices were below the reserve price. If a large enough proportion of allowances were auctioned, forward-looking market participants would anticipate a reduction in supply in the event of low prices, and adjust expectations so that market prices would be more likely to remain at or around the auction reserve price.

The logic of the approach is shown in Figure 3. In a market without auctions, participants are provided with free allocations up to quantity $Q_{Cap}$, at which point the supply curve has a vertical component. Further allowances are supplied through flexible mechanisms, such as the CDM or JI. Market prices are determined as usual at the intersection of demand and supply, which in the Figure happens to be on the $S_{CDMJI}$ portion of the curve. In contrast, in a market with auctions and a reserve price, the free allocation is reduced, and the supply curve is horizontal at the auction reserve price. The intersection of demand and supply could produce market prices above or below this reserve price, but the reserve price makes lower prices considerably less likely, particularly as the proportion of auctioned allowances increases.

[13] There is nothing wrong with very low carbon prices provided emission targets are being met and those targets have been set optimally. On the contrary, under those circumstances low prices should be welcomed. However, low prices are problematic if they reflect a suboptimally designed cap for a given commitment period, and imply much higher carbon prices in subsequent periods, Fluctuating prices between periods does not promote “when” flexibility or dynamic efficiency, and mechanisms to smooth prices between periods would contribute to rectifying this problem.

**Figure 3 Auction reserve prices may provide price support**




Source: Hepburn et al. (2006)

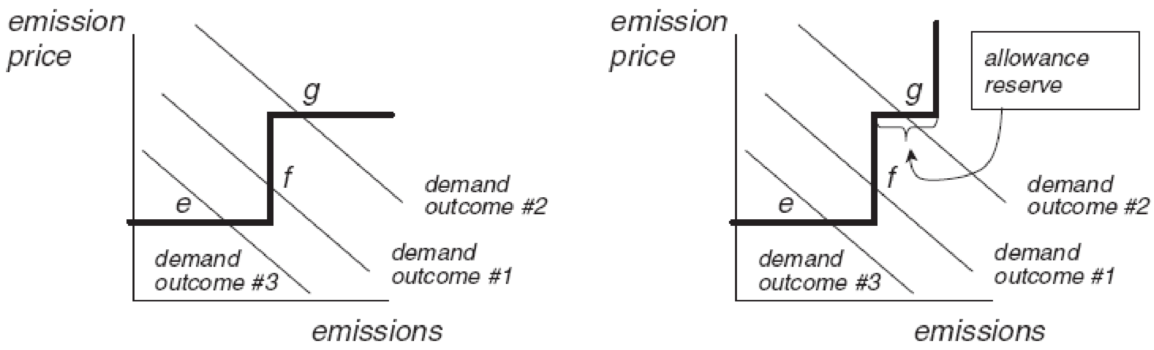
There is no inherent reason why systems with and without auction reserve prices cannot be linked together. However, there are several relevant considerations. First, the effectiveness of an auction reserve price in one system will be muted if it is linked to another system without a reserve price (or with substantial free allocation). Second, if linked market prices fall below the reserve price, the government of the system with the reserve price is obliged to curtail its supply of liquidity, thereby forfeiting the auction revenue to prop up prices in the linked system. This effectively constitutes a transfer of wealth from the system with the reserve price to the system without it. In other words, just as linking systems together requires a similarity in ambition to minimise overall transfers from one system to another, the two systems would need to have similar (but not necessarily identical) auction reserve prices in order for linking to be successful.

## 3.4 Allowance reserves

Just as very low carbon prices may be problematic, so too are very high carbon prices. Very low prices in a given commitment period might suggest that the scheme design does not reflect the dynamically efficient path. Very high carbon prices in a given period may also reflect poor system design and dynamic inefficiency. Where borrowing from a future commitment period is not feasible, some other mechanism to smooth prices may be desirable.

Establishing an "allowance reserve" as contemplated by the Waxman-Markey draft bill (Section 726), could provide a "soft" mechanism by which to manage the risk of excessively high carbon prices. The economics of an allowance reserve are not dissimilar to that of a "safety valve" or "price ceiling" (section 3.5), as shown in Figure 4. With a "price ceiling" (left figure), the emissions cap creates the vertical component of the supply curve (marked "f"), while the safety valve creates the horizontal component (marked "g"), because additional allowances are supplied elastically onto the market at the fixed ceiling price.

**Figure 4 Allowance reserves provide a limited form of cost containment**




Source: Murray et al. (2009)

An allowance reserve (right figure) is like a safety valve where a limit is placed on the number of allowances that will be issued if the safety valve is triggered. This ensures that the system delivers a defined level of emission reductions. Murray et al. (2009) provide a clear exposition of the merits of an allowance reserve.

There are no economic impediments that prevent a system without an allowance reserve from linking to a system with an allowance reserve. However, an allowance reserve, once triggered, effectively transfers wealth from the system without the reserve to the system with the reserve. This is the converse of the wealth transfers potentially involved with an auction reserve price: withholding allowances from the market would transfer wealth from the system with the auction reserve price to the system without.

In practice, these wealth transfers may create political difficulties unless (i) the levels of ambition of the two systems are set to allow for this possibility; or (ii) both systems introduce allowance reserves of roughly similar size.

## 3.5 Price ceilings and price floors

If commitment periods are short (section 3.1), banking and borrowing is limited or impermissible (section 3.2), there is no auction price reserve (section 3.3) or allowance reserve (section 3.4), then prices will probably be highly volatile and subject to damaging spikes and/or crashes. The trading system will be unlikely to send appropriate long-term signals to private actors, who are therefore unlikely to seek to minimise their costs through "when" flexibility.

In circumstances such as these, consideration may be given to the establishment of a "price collar", outside of which carbon prices would not be permitted to move. The price collar could be implemented by a "hybrid instrument" which is a carefully tailored combination of price and quantity instruments.[14] Such a hybrid instrument would make the trading scheme more "price like", which is likely to improve the economic efficiency of the system under uncertainty for a long-term stock problem such as climate change, as noted in the Introduction. Establishing a price ceiling and floor would provide significantly greater clarity to investors to deliver dynamic efficiency (in the form of optimal investment over longer timeframes). The price floor would guarantee a certain minimum return on investment in low-carbon technologies, reducing the risk faced by innovating firms. Additionally, the price ceiling may enhance policy credibility. Because it caps the costs of compliance, a ceiling reduces the risk of a policy reversal if abatement costs turn out to be injuriously high.

The price ceiling could be established through an unlimited commitment from government (or the regulating body) to sell allowances onto the market at the price ceiling.[15] A ceiling would be achieved, however, at the cost of sacrificing compliance with the emissions cap. In addition to compromising the environmental objective of the system, breaching the emissions cap might create difficulties when nations participating in the trading system are subject to international emission reduction obligations. The price floor might be established through an unlimited commitment from government (or the regulating body) to buy back allowances from the market at the price floor. The floor would be achieved at the risk of imposing a liability on the public balance sheet. If prices fall, the cost of buying allowances to support prices would be borne by the taxpayer, with particularly unappealing distributional consequences if the allowances had been freely allocated to firms in the first place.

---

[14] Hybrid instruments should be distinguished from the use of multiple instruments for the one problem (see section 3.6). Hybrid instruments have generated much interest in the climate change context, see e.g. Pizer (2002), Jacoby and Ellerman (2004) and Philibert (2009). The classic paper is Roberts and Spence (1976).

[15] Note that a penalty for non-compliance does not constitute a price ceiling unless it serves to release firms from the obligation to comply. For instance, although the European emissions trading scheme imposes penalties for non-compliance for Phase I and II of €40/t$CO_2$ and €100/t$CO_2$ respectively, excess emissions must also be offset in the following compliance period (European Commission, 2003).

In addition to these problems with price ceilings and floors, a key problem in adopting price ceilings and floors is that they create additional complexity in linking of systems together, and may even prevent linkage, reducing “where” flexibility. Ceilings and floors make linking systems considerably more complex, because relevant regions and nation-states would need to agree upon the price ceiling and/or price floor, in addition to a mechanism for implementing them. Müller, Michaelowa and Vrolijk (2001) express the view that achieving agreement on this would be a ‘political nightmare’.

# 4 Conclusion

There are compelling reasons to establish a long-term ambition for a global carbon market that affords extensive flexibility both over time and across space.

In terms of "when" flexibility, this paper draws are four key conclusions (see our companion paper, Fankhauser and Hepburn 2010, on "where" flexibility). First, the trend towards longer commitment periods is to be welcomed, as isolated three or five year periods are too short. Beyond ten years, the trade-off between a committed, clear long-term price signal for the private sector, and the flexibility for policy (and emission targets) to respond to changes in the science or abatement costs becomes more challenging. Different approaches – such as the Australian CPRS – may yield interesting insights in this respect.

Second, banking both within and between commitment periods has several advantages, and it comes as no surprise that new systems are adopting liberal banking rules.

Third, borrowing carries significant drawbacks by way of moral hazard and adverse selection concerns, and should only be permitted in a relatively limited manner, as indeed both the EU ETS and the Waxman-Markey draft bill anticipate. The limited differences in banking or borrowing rules that currently exist should not create major problems for linking systems.

Fourth, other price management policies, such as allowance reserves, auction reserve prices or hard price ceilings and/or floors, could be potential policy options to reduce price variance between commitment periods and increase dynamic efficiency and "when" flexibility. However, these policies create obstacles that will make linking much more difficult. Given that dynamic efficiency should be achievable in systems with long enough commitment periods and appropriate banking and borrowing, these additional interventions may be seen as second-best policy alternatives to setting appropriate long-term targets in systems with banking and limited borrowing.

Some of these design issues create conceptual difficulties and barriers to linking developed country systems. To some extent, there is a trade-off between "where" and "when" flexibility. Figure 1 above shows that the gains from spatial flexibility dominate those from temporal flexibility, suggesting that policy makers should be willing to compromise on the latter to secure the former. However, few temporal design features constitute insurmountable obstacles to linking developed country systems and advancing towards an overall long-run objective of establishing a global carbon market to reduce emissions.

While there are factors discussed in this paper that counsel against full liberalisation of markets across time, taking advantage of “when” (and “where”) flexibility is critical to minimising the costs of mitigating emissions and responding to climate change.

# References


Aldy, J.E. and S. Barrett (2003). "Thirteen Plus One: A Comparison of Global Climate Policy Architectures", in: *Climate Policy* 3: 373-39

Allen M.R., Frame D.J., Huntingford C., Jones C.D., Lowe J.A., Meinshausen M, Meinshausen N. (2009) 'Warming caused by cumulative carbon emissions towards the trillionth tonne' *Nature*, 458, 1163-6.

American Clean Energy and Security Act of 2009: 111th Congress, 1st Session, Discussion draft, 31 March 2009.

Baumol, W. J. and Oates, W. E., (1988), *The Theory of Environmental Policy*. Cambridge University Press, 2nd edition.

Capoor, K. and Ambrosi, P. (2009), *State and Trends of the Carbon Market 2009,* World Bank, Washington DC.

Carbon Trust (2008), *EU ETS Impact on Profitability and Trade: A Sector-by-Sector Assessment*, www.carbontrust.co.uk.

Cropper, M. L. and Oates, W. E. (1992), 'Environmental Economics: A Survey', *Journal of Economic Literature*, 30:2, 675–740.

Dales, J.H. (1968), *Pollution, Property and Prices*. Toronto: University of Toronto Press.

Edmonds, J. Clarke, L., Lurz, J. and Wise M. (2008), 'Stabilizing CO2 concentrations with incomplete international cooperation', *Climate Policy*, 8:4, 355-376.

Ellerman, D., and Buchner, B. (2007), 'The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results', *Review of Environmental Economics and Policy*, 1, 66–87.

European Commission (2009), *Towards a Comprehensive Climate Change Agreement in Copenhagen*, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2009) 39 (final), Brussels.

European Commission (2001), *Proposal for a Directive of the European Parliament and of the Council Establishing a Framework for Greenhouse Gas Emissions Trading Within the European Community and Amending Council Directive 96/61/EC*, Explanatory Memorandum. COM (2001) 581, Brussels, 23.10.2001, 5.

European Commission (2008), Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the community. Brussels, 23 January 2008. COM (2008) 16 final.

Fankhauser, S. and C. Hepburn (2010). 'Designing Carbon Markets Part II: Carbon Markets In Space', in: *Energy Policy*, forthcoming.

Government of Australia (2008), *Carbon Pollution Reduction Scheme: Australia's Low Pollution Future*, White Paper, December.

Haites, E. and Mullins F. (2001), *Linking Domestic and Industry Greenhouse Gas Emission Trading Systems*, EPRI, International Energy Agency and International Emissions Trading Association.

Helm, D. and Hepburn, C. (2007), 'Carbon contracts and energy policy', in Helm, D. (ed) *The New Energy Paradigm*, Oxford: Oxford University Press, 63-75.

Helm, D., C. Hepburn and R. Mash (2003). 'Credible Carbon Policies", in: *Oxford Review of Economic Policy* 19(3): 438-450.

Hepburn, C. (2006), 'Regulating by prices, quantities or both: an update and an overview', *Oxford Review of Economic Policy*, 22:2, 226-247.

Hepburn, C. (2007) 'Carbon trading: a review of the Kyoto mechanisms', *Annual Review of Environment and Resources*, 32, 375-393.

Hepburn, C., Grubb, M., Neuhoff, K., Matthes, F. and Tse, M. (2006), 'Auctioning of EU ETS Phase II allowances: how and why?' *Climate Policy*, 6:1, 135-158.

Hoel, M. and Karp, L. S. (2001), 'Taxes and Quotas for a Stock Pollutant with Multiplicative Uncertainty'. *Journal of Public Economics*, 82, 91-114.

International Energy Agency (2007), *World Energy Outlook 2007*. Paris, France: International

Energy Agency.

Ismer, R. and Neuhoff, K. (2009), 'Commitments through financial options: an alternative for delivering climate change obligations', *Climate Policy*, 9, 9-21.

Jacoby, H. D. and Ellerman, A. D. (2004), 'The safety valve and climate policy', *Energy Policy*, 32, 481-491.

Jotzo, F. and Betz, R. (2009). 'Australia's Emissions Trading Scheme: Opoortunities and Obstacles for Linking', *Climate Policy* 9: 402-414.

Mace, M.J., Millar, I., Schwarte, C., Anderson, J., Broekhoff, D., Bradley, R., Bowyer, C., Heilmayr, R., (2008), 'Analysis of legal and organisational issues arising in linking the EU Emissions Trading Scheme to other existing and emerging emissions trading schemes'. London, Brussels, Washington, DC: *Foundation for International Environmental Law and Development*, Institute for European Environmental Policy, World Resources Institute.

Manne A. S. and Richels R. G. (1996), 'The Berlin Mandate: The Costs of Meeting Post-2000 Targets and Timetables' *Energy Policy* 24:3, 205-210.

McKibbin, W. J. and Wilcoxen, P. J. (2002), 'The role of economics in climate change policy', *Journal of Economic Perspectives*, 16:2, 107-129.

McKibbin, W. J. and Wilcoxen, P. J. (2004), 'Estimates of the costs of Kyoto: Marrakesh versus the McKibbin-Wilcoxen blueprint', *Energy Policy*, 32, 467-479.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J. & Allen, M. (2009), 'Greenhouse gas emission targets for limiting global warming to 2°C', *Nature*, 458, 1158-62.

Metcalf, G.E. (2009). *Cost Containment in Climate Change Policy. Alternative Approaches to Mitigating Price Volatility*, NBER Working Paper 15125 ,Cambridge MA, July.

Michaelowa, A., Hayashi, D., Jung, M., Müller, N., Bode, S., Castro, P., Dransfeld, B., and Höhne, N. (2008), *A review of the current state and options for reform of the CDM*, Report for UK Department of Environment, Food and Rural Affairs, July.

Müller, B., Michaelowa, A. and Vrolijk, C. (2001) *Rejecting Kyoto: A study of proposed alternatives to the Kyoto Protocol*, London: Climate Strategies.

Murray, B. Newell, R.G. and Pizer, W.A. (2009), 'Balancing cost and emissions certainty: An allowance reserve for cap-and-trade', *Review of Environmental Economics and Policy*, 3:1, 84-103.

Newell, R.G. and Pizer, W.A. (2003), 'Regulating Stock Externalities under Uncertainty', *Journal of Environmental Economics and Management*, 45:2, 416–432.

Newell R., Pizer, W. and Zhang, J. (2005), 'Managing Permit Markets to Stabilise Prices', *Environmental and Resource Economics*, 31, 133-157.

Philibert, C. (2009). "Assessing the Value of Price Caps and Floors", in: *Climate Policy* 9: 612-633.

Pizer, W. A. (2002), 'Combining price and quantity controls to mitigate global climate change', *Journal of Public Economics*, 85, 409-434.

Richels, R., Edmonds, J., Gruenspecht, H. and T. Wigley (1996), 'The Berlin Mandate: The Design of Cost-Effective Mitigation Strategies', in N. Nakicenovic, W.D. Nordhaus, R. Richels and F.L. Toth (eds.), *Climate Change: Integrating Science, Economics and Policy*, IIASA CP-96-1, International Institute for Applied Systems Analysis, Austria, 229-248.

Roberts, M. J. and Spence, M. (1976), 'Effluent charges and licences under uncertainty', *Journal of Public Economics*, 5, 193-208.

Smith, V. L., Suchanek, G. L. and Williams, A. W. (1988), 'Bubbles, Crashes, and Endogenous Expectations in Experimental Spot Asset Markets', *Econometrica* **56**(5), 1119–1151.

Stavins, R. N. (1995), 'Transaction Costs and Tradeable Permits', *Journal of Environmental Economics and Management*, 29, 133-148.

Stern, N. (2007). *The Economics of Climate Change. The Stern Review*. Cambridge: CUP.

Stern N. H., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., et al. (2007), *Stern Review:* The Economics of Climate Change, Cambridge University Press, Cambridge, UK.

Vivid Economics (2008), *Peer Review: Reform of the Clean Development Mechanism*, Report for UK Department of Environment, Food and Rural Affairs, August.

Vrolijk C. and Grubb M. (1999), 'Quantifying flexibility in combating climate change: modelling the implications of flexibility mechanisms in the climate change negotiations', *International Journal of Environment and Pollution*, 11(4), 495-524.

Weitzman, M. L. (1974), 'Prices vs. Quantities', *Review of Economic Studies*, 41(4), 477-491.

# Appendix

Section 2.1 determined results to describe the impact of different policy instruments on price volatility under linear supply and demand schedules for permits. This Appendix develops equivalent results for isoelastic demand and supply.

If demand for permits $Q_d$ from firms is isoelastic, it is given by:

$$\log Q_d = \gamma_d - \varepsilon_d \log P \qquad \text{(A1)}$$

where $P$ is the permit price, $\varepsilon_d$ is the demand elasticity and $\alpha_d$ is a demand parameter. The supply of permits is determined by policy. To allow for a general analysis, suppose the supply if permits is also isoelastic, and given by:

$$\log Q_s = \gamma_s + \varepsilon_s \log P \qquad \text{(A2)}$$

where $\varepsilon_s$ is the supply elasticity and $\gamma_s$ is a parameter. When supply is infinitely elastic, $\varepsilon_s = \infty$, policy is effectively a pure carbon tax. When supply is inelastic, $\varepsilon_s = 0$, policy is a pure carbon trading scheme. Hybrid schemes allow for intermediate values.

The clearing price in the model is given by:

$$P = \exp\left(\frac{\gamma_d - \gamma_s}{\varepsilon_d + \varepsilon_s}\right) \qquad \text{(A3)}$$

If demand is uncertain and distributed normally such that:

$$\gamma_d \sim N(\bar{\gamma}_d, \sigma_\alpha^2) \qquad \text{(A4)}$$

Denote $\varphi = \left(\frac{\gamma_d - \gamma_s}{\varepsilon_d + \varepsilon_s}\right)$, so that $\varphi$ is also normally distributed with $\varphi \sim N\left\{\left(\frac{\bar{\gamma}_d - \gamma_s}{\varepsilon_d + \varepsilon_s}\right), \left(\frac{\sigma_\alpha}{\varepsilon_d + \varepsilon_s}\right)^2\right\}$. It follows that $P = \exp(\varphi)$ is lognormally distributed with variance:

$$var(P) = \left[2\, exp\left(\frac{\sigma_\alpha}{\varepsilon_d + \varepsilon_s}\right) - 1\right] . \exp\left[2\left(\frac{\bar{\gamma}_d - \gamma_s}{\varepsilon_d + \varepsilon_s}\right) + \left(\frac{\sigma_\alpha}{\varepsilon_d + \varepsilon_s}\right)^2\right] \qquad \text{(A5)}$$

$$(\partial var\ (P))/(\partial \varepsilon_{\downarrow} s\ ) = -[2\sigma_{\downarrow}\alpha\ \ (1/(\varepsilon_{\downarrow} d + \varepsilon_{\downarrow} s\ ))^{\uparrow}(-2)\ exp(\sigma_{\downarrow}\alpha/(\varepsilon_{\downarrow} d + \varepsilon_{\downarrow} s\ ))\ ].\mathbf{exp}[2((\bar{\gamma}_{\downarrow} d - \gamma_{\downarrow} s)/(\varepsilon_{\downarrow} d + \varepsilon_{\downarrow} s \qquad \text{(A6)}$$

In other words, as with linear demand and supply as in section 2.1, if a policy maker increases the supply elasticity $\varepsilon_s$, for instance by moving from a carbon trading scheme, with a fix cap an inelastic supply of permits ($\varepsilon_s = 0$), to carbon taxes where supply is perfectly elastic ($\varepsilon_s \rightarrow \infty$) will reduce price volatility.