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Carbon markets in space and time

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Abstract

This paper analyses the design of carbon markets in time (intertemporally) and space (geographically) from first principles, starting initially with a relatively clean slate and asking what an optimal global carbon market would look like by around 2030. Our focus is on firm-level trading systems, although much of what we say would also apply to government-level trading (e.g., AAU trading under the Kyoto Protocol). We examine the "first principles" of design to maximise flexibility and to minimise costs, consider temporal design including banking and borrowing and other mechanisms to provide greater carbon price predictability and credibility over time, and consider spatial elements, examining the key design issues in linking national and regional carbon markets together to create a global carbon market.

1 Introduction

The world is embracing carbon markets. Despite the onset of a global recession, carbon trading breached the $100 billion mark in 2008, up from $64 billion in 2007 (Capoor and Ambrosi, 2008). 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. As the world embarks on creating a global carbon market, this is a good moment to recap the economic case for carbon trading and review market design options, as it is important to get the basic structure right.

The world's largest carbon market to date is the EU Emissions Trading Scheme ("EU ETS"), which covers over 40% of EU carbon dioxide emissions, or about 2 $GtCO_2$. In December 2008, EU member states agreed to extend the scheme until at least 2020 and open it up to new sectors, most notably aviation. Other European countries like Norway, Iceland and Switzerland already have or could soon link up with the EU ETS.

The new US administration wants to make cap-and-trade a key plank of its climate policy. The proposals currently contemplated by US lawmakers would create a US-wide carbon market within 5-6 years which would be two or three times bigger than the EU ETS. Canada has signalled that it might abandon its own carbon trading plans (an efficiency-based system) and link up with the US system. Carbon trading in North America started in earnest in January 2009 with the official launch of the Regional Greenhouse Gas Initiative (RGGI) of 10 north-eastern States.

With the two antipodean systems – Australia's Carbon Pollution Reduction Scheme (CPRS) and New Zealand's Emissions Trading Scheme (NZ ETS) – also in different stages of development, Japan remains the only major developed economy that is not actively considering carbon trading. Even in Japan positions are shifting. It is not inconceivable that the proposal of an OECD-wide market by 2015, advanced by the European Commission in its post-2012 communication (European Commission, 2009), could eventually come to pass.

Last but not least, the expansion and reform of the Clean Development Mechanism (CDM) — the world's largest baseline-and-credit system — is a key aspect of the international negotiations for a new global deal. Negotiators have made it clear that they wish the Kyoto mechanisms to continue beyond 2012, but which form they will take is still open to debate. Various options to support international carbon finance flows are being actively discussed, including sectoral crediting mechanisms which would deliver credits for emission reductions from entire sectors, ironing out the remaining wrinkles in programmatic CDM which would permit the credits to be granted for programmes that aggregate many small emission reducing activities, and so on (Vivid Economics, 2008; Michaelowa et al., 2008).

Behind the global interest in carbon markets is the recognition that any meaningful climate change policy has to put a price on carbon (Stern 2007). This is a fundamental, if fairly basic, lesson from environmental economics and the theory of externalities (Baumol and Oates, 1988; Cropper and Oates, 1992). Environmental economics also tells us that there are several ways of putting a price on carbon, including taxes, permits and any number of hybrid instruments. Under textbook assumptions they are essentially equivalent, but in real world situations with imperfect information, transaction costs and external shocks, there are important differences between trading, taxes and hybrid systems (Hepburn, 2006).

The key reference on taxes versus permits remains Weitzman (1974), who showed that if compliance costs are uncertain the choice of instrument depends on the relative curvatures of the marginal benefit curve and the marginal abatement costs curve. Hoel and Karp (2001) and 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. These papers suggest that a carbon tax is more economically efficient under uncertainty than emissions trading. In practice, however, the Weitzman analysis of efficiency under uncertainty has had little influence on the choice of policy instruments. The preference for carbon trading over carbon taxes is driven largely by powerful political economy concerns (Hepburn, 2006, 2007). Trading systems are easier to implement politically.

Perhaps more important is the fact that in reality the choice between taxes and permits (or allowance-based systems) is not strict. There are ways to create hybrid instruments that blend price-based and quantity-based features. Like all markets, the market for emission reductions has a demand schedule, which is determined by the marginal abatement costs of regulated agents, and a supply schedule, 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 create a supply curve that is neither fully flat (a pure tax) nor fully vertical (pure cap-and-trade) but (stepwise) upward sloping. It is intuitive to think that hybrid instruments, with their conventional supply curve, hold as much promise as the extreme cases. We will return to this later in the report. The point to note here is that the slope of the supply curve is an issue of market design and not predetermined by the choice of instrument.

The shape of the supply curve is only one of many design choices policy makers have to make. Others include:

- The allocation of allowances creates economic rents and therefore matters a great deal to the political viability of any system (Hepburn, 2006). In many cases allocation may also influence the efficiency of the system (Stavins, 1995; Hepburn et al., 2006)
- Links with other instruments are critical for climate policy, because carbon markets will inevitably be supplemented by other instruments, so instrument interaction matters. Regulations are often directed at internalising externalities, and the simple theory of externalities indicates that only one instrument is needed to internalise one externality. However, several exernalities in addition to the greenhouse gas externality are relevant to climate change, including externalities relating to innovation and R&D. These other externalities may be addressed through separate policy levers that supplement a price of carbon. In addition, political distortions may imply that even attempts to internalise the carbon price are suboptimal, such that carbon prices are well-below the social cost of emissions, supporting the case for supplementary interventions to increase coverage or to lift long-term prices.
- Transaction costs matter with regard to design choice. Some systems are easier to administer than others. For instance, upstream trading systems have fewer (and more sophisticated) trading entities than, say, downstream trading between individual consumers. Another example is that baseline and credit systems, such as the Clean Development Mechanism, have inherently higher transaction costs than cap and trade systems, because asymmetric information requires costly signalling to prove additionality (Vivid Economics, 2008).
- Temporal issues also matter enormously, given the long-term nature of climate change. The rule on banking and borrowing of allowances within and between periods can have strong effects on the liquidity and efficiency of the trading system, as the report discusses more extensively in section 3.

It is not the purpose of this report to deal with all of the issues above. Rather we focus on the key issue that makes carbon markets a cost-effective instrument for emission control: the flexibility to spread emission reductions across space and over time. It is this "where flexibility" and "when flexibility" that allows markets to minimise compliance costs. In principle, the more "where" and "when" flexibility is built into market design, the more cost-effective a market is likely to be.

However, there are factors that may counsel against full liberalisation of markets across space and time. For example, different levels of ambition in different jurisdictions may prevent the linking of regional markets. Similarly, most markets limit intertemporal arbitrage — the amount of banking and borrowing — to avoid time inconsistency problems. In this report, we explore some of these factors and suggest design options that may help to overcome them.

Woven throughout our arguments will be a second issue: the volatility in the carbon price. Undue price fluctuations have been an important concern of policy makers, both upward (e.g. the call for safety valves in the US and Australian discussion) and downward (for example the recent drop in EU allowance prices and the price collapse in phase I). We will highlight this issue where relevant to other temporal considerations. In so doing, we distinguish between market-induced volatility and volatility resulting from or exacerbated by regulatory design. The former is a natural feature of any well-functioning market and may reflect changes in underlying fundamentals (for example a change in oil prices). The latter is undesirable and should be minimised through appropriate market design.

Linking markets is one way of reducing regulatory-induced volatility, as price volatility and market flexibility are linked. The more integrated a market is across space and time, the less volatile prices should be, all else being equal. With deeper markets, a shock to any one region will have a smaller impact on the global carbon price than it would have had on a regional carbon price in an autarkic, smaller market. While linking to other regions also creates exposure to shocks in those other regions, overall market integration might be expected to reduce price volatility (Jacks et al., 2009). In fact, in some cases price volatility is a direct consequence of market design and/or policy shocks, rather than being caused by natural market fluctuations.

This report considers the design of carbon markets in time and space from first principles, starting initially with a relatively clean slate and asking what an optimal global carbon market would look like by around 2030. Our focus is on firm-level trading systems, although much of what we say would also apply to government-level trading (e.g., AAU trading under the Kyoto Protocol). Section 2 sets out some "first principles" of design that are woven throughout the rest of the report. In section 3, temporal design elements are considered, including banking and borrowing and other mechanisms to provide greater carbon price predictability and credibility over time. Section 4 turns to spatial elements, examining the key design issues in linking national and regional carbon markets together to create a global carbon market. Section 5 concludes.

2 First principles of carbon market design

2.1 Maximise "where" and "when" flexibility

The cost-effectiveness of our efforts to reduce emissions will be critical to the success or failure of climate policy, for two reasons. First, the world's willingness to pay is limited; there are always many worthy claims to attention and funds. As such, achieving stabilisation of atmospheric carbon dioxide concentrations at 450-550 ppm will require that the available funds are spent wisely. Second, climate change is such a significant global challenge that (i) the costs of reducing emissions are expected to be substantial – at least 1% of GDP (Stern, 2007; IEA 2007) [1]; and (ii) those costs are a strong function of policy choices. It is thus extremely important that the world tackles mitigation in a cost-effective way.

Costs are reduced by allowing flexibility about where and when emissions reductions occur. Integrated assessment modellers have long recognised this. For instance, in 1996 the Stanford Energy Modeling Forum noted that the cost of the then Berlin Mandate (the process that resulted in the Kyoto Protocol) could be reduced to a fraction of the total by introducing spatial and temporal flexibility (Richels et al. 1996; Manne and Richels, 1996). This conclusion has proven robust to specific models and particular policies (e.g. Vrolijk and Grubb, 1999), as indeed would be expected. A recent example is the work by Edmonds et al. (2008) on the cost of delaying developing country participation in the global deal. Indeed, under certain plausible conditions it is theoretically inevitable that providing more options reduces costs.[2]

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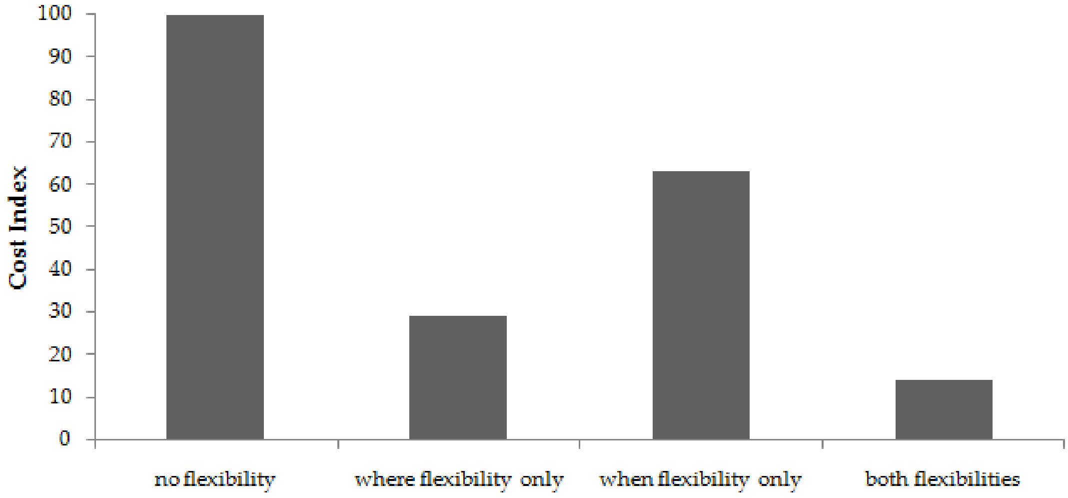
[1] Of course, it is expected that these costs will be hugely outweighed by the benefits from mitigating climate change (Stern, 2007).

[2] For a study of the relationship between choice and welfare, see Irons and Hepburn (2007).

Figure 1 Cost reductions from allowing "where" and "when" flexibility



Source: Richels et al (1996)

This insight on the value of "where" flexibility is significant. It suggests that, *ceteris parabis,* our ambition should be a "global" carbon market. In practice, there are various caveats and constraints on implementing such a market, discussed in section 2.2. Nevertheless, something approximating a global carbon market might be created by "linking" different national and regional trading systems. Linking markets not only increases "where" flexibility, it also increases liquidity, because there are more willing buyers and sellers, which reduces the costs of trading. In contrast, fragmented and unconnected national carbon trading systems would be less liquid, or "thinner", with concomitantly higher costs of reducing emissions.[3]

Similarly, theoretical insights on "when" flexibility suggest a market with long-term commitment periods, or "phases", or full scope for banking and borrowing of allowances between commitment periods to allow firms to optimise the time at which they reduce emissions. 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.

The length of the commitment period is important because (i) unlimited banking and some

[3] The new Carbon Reduction Commitment in the United Kingdom may suffer from problems of limited liquidity (Defra, 2008).

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]

A market with long-term commitment periods and/or banking and borrowing not only increases "when" flexibility, it also increases liquidity. 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 (see section 2.2).

2.2 Constraints prevent a global market

In reality, there are political and economic constraints preventing a global carbon market from emerging. Some of these constraints are not particular to carbon markets. For instance, the "global markets" for oil, wheat and gold are in fact complex trading systems where location, quality and time matter. Carbon will most likely be the same, and it would be surprising if there were a single, globally uniform carbon price.

In terms of "where" flexibility, there may be constraints in linking up systems because of:

(i) inherent differences in the traded good. For instance, "forest carbon" from afforestation or reforestation schemes raises questions of permanence (Eliasch 2008). Aviation emissions involve complex scientific issues of radiative forcing at altitude, and various other sectors, including agriculture for instance, involve the conversion of other greenhouse gases into carbon dioxide equivalents;

(ii) excessive cost differences. While the point of emissions trading is to maximise "gains from trade" (section 3.1), political considerations demand that transfers are not "too large". For instance, one of the controversies surrounding HFC projects under the CDM was the amount of economic rent generated (Hepburn, 2007). The carbon market was seen as too expensive a way to phase out HFCs, which is relatively cheap to do; and

(iii) policy differences, primarily due to differences in the level of ambition of different systems. Differences in ambition manifest themselves in different carbon price levels that are deemed unacceptable.

[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.

In terms of "when" flexibility, the main constraint is on the extent to which firms can borrow, rather than bank, allowances between commitment periods, 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;
(ii) borrowing enables firms to delay action if they assume that targets will prove too onerous and will subsequently be softened;
(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.
(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 carbon trading framework. These uncertainties significantly increase risk and reduce the likelihood of low-carbon investments being made (Helm, Hepburn and Mash, 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,

[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

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. This flexibility 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]

Next we turn to design features that can overcome some of these problems, while maintaining "where" and "when" flexibility.

[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 Spatial design: "where" flexibility

The first principles of carbon market design point to a theoretical ideal of a global market with full "where" flexibility. Given the geographical distribution of low-cost mitigation opportunities (McKinsey 2009), only a global market will ensure full cost-efficiency.

A truly global carbon market with uniform rules and a global regulatory regime is unlikely to emerge for many years. However, a system of connected and coordinated regional markets can be an alternative that provides similar efficiency gains. Even established global markets like that for oil, wheat or coal are systems of separate but highly integrated regional markets with distinct local supply and demand dynamics. The most likely way in which a global carbon market will emerge is through increasingly closer links between regional trading systems.

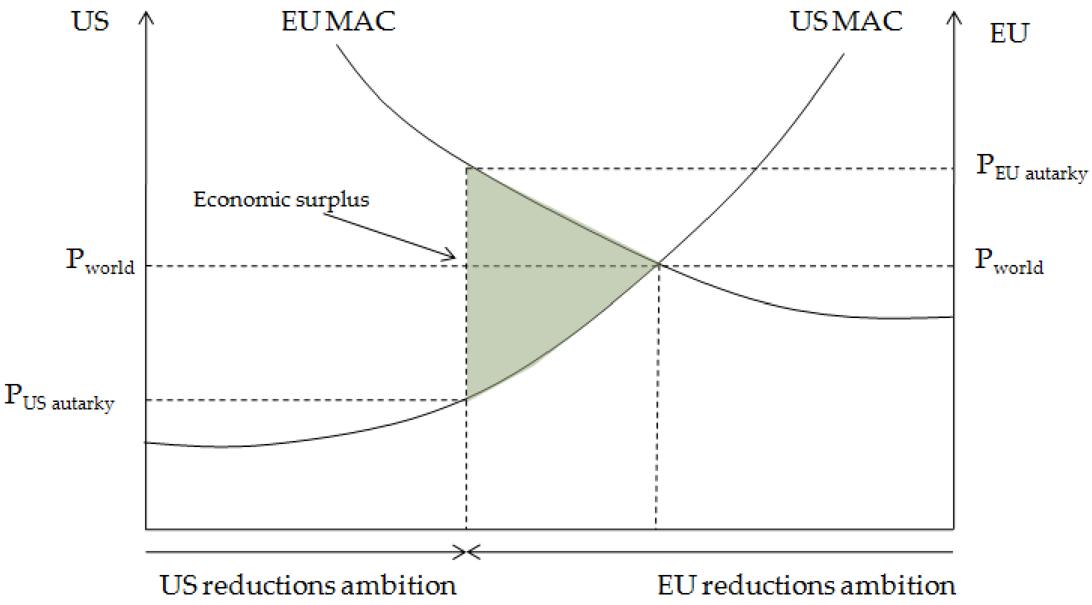
Linked markets will create trading opportunities, financial flows and "rents", or gains from trade (section 3.1). Linking regional markets requires a certain level of coordination and the alignment of policy objectives between the systems. Perhaps the most important objective upon which agreement is required is the range of acceptable carbon prices, as prices in linked systems will invariably converge through arbitrage. That is, there has to be an *equivalence of ambition* between systems (section 3.2). There is also a need for coordination on market rules such as allowance allocation, the treatment of offsets and quality standards, e.g. in terms of monitoring (section 3.3). The more integrated a market is, the lower are concerns about carbon leakage and the loss of competitiveness. If markets are insufficiently linked and "unilateral", a key concern for market design is how to address leakage and competitiveness issues (section 3.4).

3.1 The gains from trade

A key feature of integrated markets – and in fact the source of the efficiency gains – is that it allows the arbitrage of price differentials until there is a uniform price across the system.

Figure 2 shows this effect schematically. Emission reductions in the first country (in our hypothetical example, the US) are measured from left to right, those of the second country (the EU) are measured from right to left. The width of the graph denotes the combined abatement effort. Before markets are linked up we will observe a different autarky price in each system. Once the two markets are joined up we will observe a net flow of allowances from the low-price system (the US in this example) to the high-price system (the EU) until there is a uniform price. Higher marginal abatement costs in the EU means that EU firms find it optimal to purchase allowances from US firms instead of reducing emissions at home.

Figure 2 Hypothetical gains from linking US and EU trading systems



The activity generates economic benefits in the size of the shaded area: High-cost abatement in the EU is replaced with cheaper abatement in the US. At the firm level, EU firms benefit from reduced costs of compliance, and US firms profit from selling their excess allowances at higher prices than they would achieve in the domestic US system. The size of the gains from trade depends upon the shape of the marginal abatement cost curves of the trading regions, and the respective ambition of the two systems.

If the linking systems are identical in ambition, such that carbon prices are identical in autarky, then there are no immediate gains from trade. However, there are benefits from increased liquidity. Furthermore, Figure 2 only presents a static analysis; in reality the location of the marginal abatement costs will shift as new technologies are discovered, and indeed as the market price of other key commodities (such as coal and gas) move. These dynamic movements imply that even systems of roughly equivalent ambition would have wide variances in prices without linking between them.

3.2 Equivalence of ambition

Linking markets requires that policy makers in both systems have similar levels of ambition and expectations about the carbon price. The equilibrium price P_{world} in Figure 2 has to be within an acceptable range for both jurisdictions.

This seems obvious but is in fact the main stumbling block in linking up markets. The EU more or less explicitly aspires to a high-price system that ultimately supports technologies like Carbon Capture and Storage. In much of the rest of the world, most notably the US, the concern is more about avoiding price spikes. As long as levels of ambition are not aligned regional markets will not be linked for political reasons, and if they were they would function badly.

Imagine a linked up system such as that in Figure 2 where regulators in both systems have the ability to intervene in the market. The following undesirable scenario could occur. In the low-price system, a safety valve or other mechanism might be triggered as arbitrage pushes the price up to the equilibrium level (for example, through the issuance of additional allowances or increased offset limits). In the meantime, the high-price regulator might seek to support the price by withdrawing allowances or imposing an auction reserve price above P_{world}. The two sets of action will cancel each other out (unless one regulator has more market power than the other). In the process they will increase the flow of allowances from the low-price to the high-price system. Market intervention exacerbates the ex-ante differences. The low-price system becomes even more low-price (in terms of the autarky price) as the level of ambition is scaled down, and the reverse happens in the high-price system.

A second issue is the acceptance of the financial transfers and trade flows that integration will bring. They are depicted graphically in Figure 3. The low-cost system (in our example, the US) can expect carbon market revenues in the magnitude of the shaded rectangle. Depending on the shape of the abatement cost curves and the levels of domestic ambition, cross-border flows may be significant relative to overall trading volumes. For example, in 2008 UK firms participating in the EU ETS were 24% over their allowed cap and had to buy a net 50 million allowances from firms in other countries. German firms were 21% short and had to import 84 million allowances. [11] Combined, these transactions were worth in excess of €2.5 billion.

This is a small sum relative to overall trade flows. The UK imports goods and services worth over €500 billion each year Nevertheless, the size and direction of trade flows is likely to matter when systems are linked up, and particularly when they are caused by differences in the level of ambition (a policy choice), rather than abatement costs (a technical-economic issue). Few policy makers will be willing to reward low levels of ambition with additional financial flows from carbon market arbitrage.

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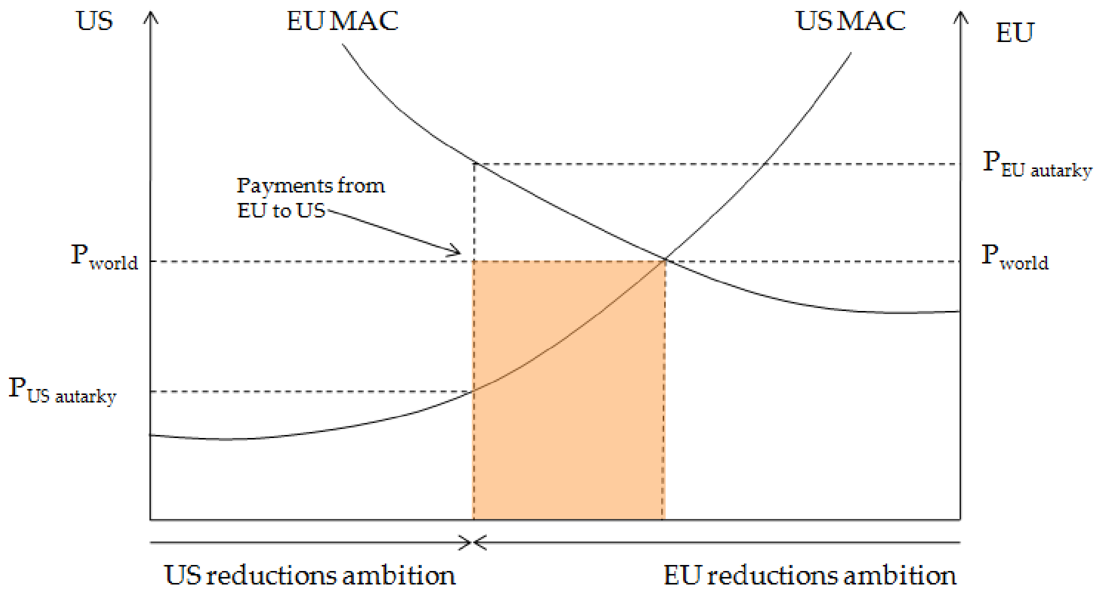
[11] Data from http://communities.thomsonreuters.com/Carbon/. A fraction of the shortfall may also have been borrowed from the 2009 allowance pool (see section 4.1).

Figure 3 Hypothetical payments from EU firms to US firms



3.3 Compatibility of system design

Linking trading systems requires a minimum level of coordination on market design or the combined markets will not function properly. We have already seen the impact of differing price policies (price support vs. safety valves) in the previous section. It is not the only area where coordination will be necessary (Sterk et al., 2009).

One major area where consistency across systems is crucial in the longer term is allowance allocation. In isolated markets (and in the early stages of a system) allowances tend to be issued for free, particularly to installations that are subject to international competition. The belief is that this can help to mitigate negative impacts on competitiveness. We will discuss the merits of this approach in the next section. Whatever they may be, they fall away once the competition is also capped under a linked emissions trading system and therefore subject to the same carbon price. In that case free allocation becomes a form of state aid that gives its recipients a competitive advantage over rivals that have to purchase their allowances. To avoid market distortions, linking up regional systems has to go hand-in-hand with an alignment in allocation rules.

This is the reason why allocation rules within the EU ETS are coordinated at EU rather than national level. As a consequence, differences are small (although there are some). The only sector where there are substantial differences in allocation rules is electric power, where some Central European power producers will enjoy softer auctioning rules than their Western peers in phase III of the system. However, the derogation is temporary and there is relatively little cross-border electricity trading in Europe so the competitiveness effect is small.

Another area where coordination across systems is important is the treatment of carbon offsets, such as certified emission reductions from the CDM. There has to be alignment both in terms of the quality (environmental integrity) and the quantity of offsets permitted into a system. Most cap and trade systems limit the number of offset credits that can be imported into the system. The current version of the Australian Carbon Pollution Reduction Scheme is a notable exception (Government of Australia, 2008). Different systems also impose varying degrees of quality requirements. The EU ETS, for example, does not recognise forestry credits. Once systems are linked any such differences disappear de facto. Credits may enter the market through the national system with the most permissive rules, where they can be swapped into freely tradable allowances.

3.4 Competitiveness issues

One of the main questions in designing a unilateral cap-and-trade system is how to prevent carbon leakage and the loss of international competitiveness. The two issues are linked. Leakage and competitiveness are the environmental and economic side of the same coin.

Firms facing higher production costs due to carbon regulation are at a disadvantage in the international market and will lose market share to competitors with less stringent carbon constraints. Multinational firms may choose to relocate production to avoid carbon regulations. In either case, emissions and economic activity move away from the regulated space to less-strictly regulated regions. Even if this does not happen, mitigation action in the regulated market could lead to a fall in the demand of high-carbon fuels like coal, whose price will drop as a consequence. This will in turn stimulate demand (and reduce the cost base) outside the regulated market. The result is again carbon leakage and a loss in competitiveness.

The problem is most acute between regulated and unregulated markets but it applies similarly to regions with different carbon prices and different levels of ambition. Most studies suggest that competitiveness issues are restricted to a small number of sectors (Carbon Trust 2008). Nevertheless it is an important concern.

Competitive issues become smaller the wider and more integrated the carbon market becomes as an increasing share of a sector is covered by equivalent regulation. Linking is therefore the first-best-choice of resolving competitiveness problems and preventing leakage.

If linking is not possible the next best solution is to create a level playing field in those sectors where international competition is particularly strong and the problem thus most acute. In some cases, it may be feasible to create a fully-fledged sector-level trading system. International shipping is one sector where this is contemplated. In other cases it may help to impose similar regulatory requirements on firms inside a trading system (through a carbon price) and outside the system (through equivalent regulation). Sector agreements are contemplated, for example, in steel. However, they are difficult to set up because production processes and national circumstances differ, which makes it hard to define meaningful technical benchmarks.[12] Other problems arise, including the challenge of creating incentive for participation by companies in non-regulated regions, and ensuring compliance and enforcement.

The favourite instrument to address competitiveness issues, at least in the EU, has so far been the free allocation of allowances to installations that are subject to international competition.[13] From an economic point of view, the effectiveness of this measure is uncertain. Free allocation does not change the value of allowances and should therefore not affect the behaviour of firms at the margin. An allowance has the same opportunity cost whether it has to be purchased on the market or was received for free. Free allocation may make a difference, though in the presence of transaction costs or firm-internal dynamics. Relocating factories is costly, particularly if unions and local stakeholders are involved, and may affect a firm's standing in the home market. Perhaps demonstrating profitability (however achieved) is sufficient for managers to keep an installation open. However, such short-term arguments become less convincing once a trading system has been operational for a few years.

The final alternative to deal with competitiveness problems is border tax adjustments. This option is discussed for example by Brewer (2004) and Ismer and Neuhoff (2007).

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[12] Vivid Economics (2008) and Michaelowa et al. (2008) provide a discussion of sectoral trading approaches.

[13] Free allocation is also a way to obtain buy-in from industry and to compensate stranded assets created through abrupt regulatory change. In political economy terms this is a key reason why cap-and-trade systems are easier to implement than a carbon tax.

4 Temporal design: "when" flexibility

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.

4.1 Commitment period length

Section 2.2 noted that banking and borrowing are often permitted (at least to some extent) within but not necessarily between commitment periods.[14] 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.

[14] 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.

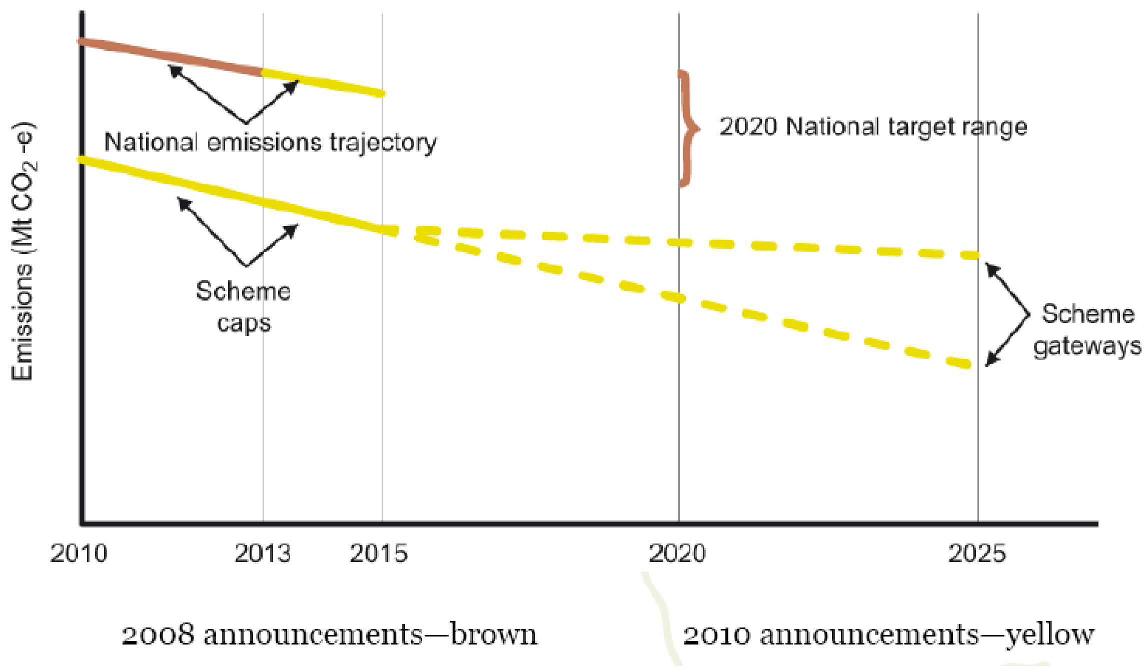
Longer periods not only maximise “when” flexibility, they also reduce price volatility, and provide the private sector with longer-term price signals which, if credible, should spur innovation and investment. However, longer periods reduce policymakers’ flexibility to adjust targets in response to changing 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 too 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). 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 4. 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 4 Caps and gateways in the Australian CPRS



Source: Government of Australia (2008)

4.2 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).

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, Pizer and Zhang (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 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 2.2, namely that:

- the government may not be well-equipped to assess the credit worthiness and solvency of firms who borrow allowances, thereby becoming debtors. The usual mechanisms, such as the provision of collateral, may be deployed to mitigate this risk, but this would add transaction costs and complexity;
- firms which are least solvent are likely to want to borrow more than firms which are most solvent (a form of *adverse selection*);
- borrowing allows firms to delay action if they believe that targets will prove too onerous and will subsequently be softened;
- 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 reduced or cancelled (a form of *moral hazard*).

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 in section 4.1 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.

4.3 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 4.4), or establish more rigid price ceilings or floors (section 4.5).

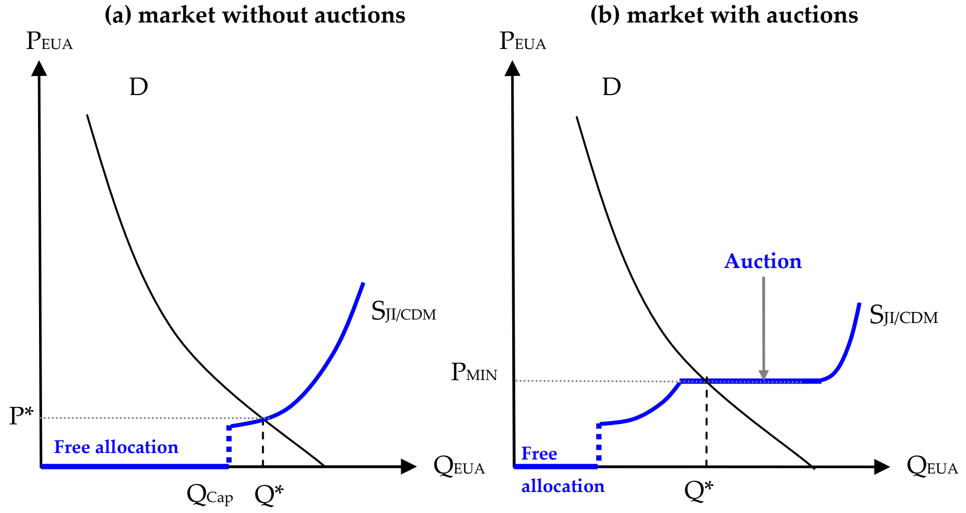
As the proportion of allowances allocated by auction increases, one "soft" approach to managing the risk of low carbon prices[15] is to set a reserve (or minimum) price for the periodic auction of the allowances, such that no allowances would be sold onto the market if the reserve price was not reached (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 5. In a market without auctions, participants are provided with free allocations up to quantity Q_{Cap}, at which point the supply curve has a

[15] 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.

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.

Figure 5 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.

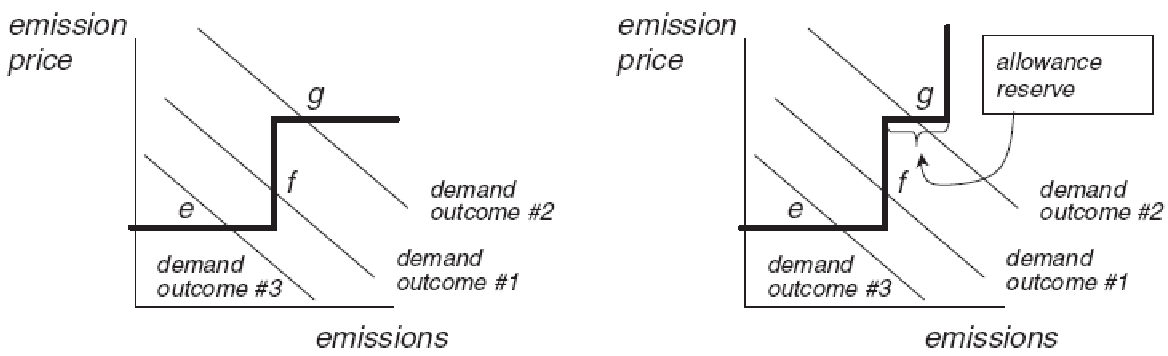
4.4 Allowance reserves

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 4.5), as shown in Figure 6 below. 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.

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. (2008) provide a clear exposition of the merits of an allowance reserve.

Figure 6 Allowance reserves provide a limited form of cost containment



Source: Murray et al. (2008)

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.

4.5 Price ceilings and price floors

If commitment periods are short (section 4.1), banking and borrowing is limited or impermissible (section 4.2), there is no auction price reserve (section 4.3) or allowance reserve (section 4.4), 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.[16] 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 to this report. 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.[17] A ceiling

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[16] 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) and Jacoby and Ellerman (2004). The classic paper is Roberts and Spence (1976).

[17] 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/tCO_2 and €100/tCO_2 respectively, excess emissions must also be offset in the following compliance period (European Commission, 2003).

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.

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’.

5 Conclusion

There are compelling reasons to establish a long-term ambition for a global carbon market. We have defined the 'global carbon market' not in the sense of a globally administered and regulated trading regime, but in the sense of a mosaic of regional and national markets that are linked and whose level of ambition is consistent with the overarching aims of climate change policy. National or regional carbon markets may be linked directly (presumably with import limits) or indirectly through common products like CERs or forest offsets that are accepted in all systems.

The current flurry of national and regional initiatives to set up carbon markets is a welcome opportunity for experimentation and innovation, allowing the opportunity to explore different designs. But there is also a risk that the results will create incompatibilities that limit the potential for linking and result in a fragmented global market in which the benefits of "where" flexibility are not fully explored.

There is merit in experimentation and learning. The concept of emissions trading is not new (Dales, 1968), and nor is the practice of emissions trading, but carbon markets on the scale, ambition and planetary importance of those currently emerging have never been seen before. We do not yet have all the answers on how these carbon markets should be designed and implemented. For example, the experience with phase I of the EU ETS has resulted in important lessons on auctioning, banking and information release that have now been incorporated in the design of subsequent systems. Experience with RGGI has also been enlightening. Continued innovation generates valuable lessons.

However, the right balance has to be found between experimentation and the need to make systems compatible so that they can eventually be linked up. The gains from trade (section 3.1) from linking are potentially enormous, even if the linked systems have identical estimated ambition (and hence carbon price) *ex ante*. Design features that may generate political or economic obstacles to linking include: differences of ambition, treatment of free allocation vs auctioning, price management policies (including price ceilings, price floors, allowance reserves, auction reserve prices), rules on borrowing, and treatment of offsets. While design differences along these dimensions do not necessarily prevent linking, they contribute to increased economic issues, design problems or political concerns about financial flows from one system to the other.

In terms of "when" flexibility, there are four key conclusions. 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, much of the benefits from spatial flexibility come from trading with developing countries (that is, the extended use of offsets), rather than linking developed country systems. This would speak against linkages that are achieved at the price of tighter limits on offsets.

The main design features that create barriers to the linking of systems are the rules on banking and borrowing and the presence of price control mechanisms if they underpin diverging views about the appropriate level of ambition (and hence prices). However, few of them constitute an insurmountable obstacle 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 report that counsel against full liberalisation of markets across space and time, taking advantage of "when" and "where" flexibility is critical to minimising the costs of mitigating emissions and responding to climate change.

References

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.

Brewer, T. L. (2004), 'The WTO and the Kyoto Protocol: Interaction Issues', *Climate Policy*, 4, 3-12.

Capoor, K. and Ambrosi, P. (2008), *State and Trends of the Carbon Market 2008,* 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.

Defra (2008), *Implementation proposals for the Carbon Reduction Commitment (formerly the Energy Performance Commitment): Review of Consultation Responses*, London: Department for Environment, Food and Rural Affairs, March.

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

Eliasch, J. (2008), *Climate Change. Financing Global Forests*. *The Eliasch Review*, London: Earthscan.

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.

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.

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., 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.

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

Hepburn, C. (2009), 'International carbon finance and the Clean Development Mechanism', in Helm D. and Hepburn C. (eds) *The Economics and Politics of Climate Change*, Oxford: Oxford University Press, chapter 20, forthcoming.

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.

Irons, B. and Hepburn, C. (2007) 'Regret theory and the tyranny of choice', *Economic Record*, 83:261, 191-203.

Ismer, R. and Neuhoff, K. (2007), 'Border tax adjustment: a feasible way to support stringent emission trading', *European Journal of Law and Economics*, 24:2, 137-164.

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

Jacks, D. S., O'Rourke, K.H. and Williamson, J. G. (2009), 'Commodity price volatility and world market integration since 1700', NBER Working Paper No. 14748, February.

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

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.

McKinsey (2009), 'Pathways to a low-carbon economy. Version 2 of the Global Greenhouse Gas Abatement Cost Curve.' London: McKinsey & Company.

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.

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.

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.

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

Sterk, W., Braun, M., Haug, C., Korytarova, K., and Scholten, A. (2006), 'Ready to Link Up? Implications of Design Differences for Linking Domestic Emissions Trading Schemes', *Wuppertal: Wuppertal Institute for Climate, Environment and Energy* (JET-SET Working Paper

I/06).

Sterk, W., Mehling, M. and Tuerk, A. (2009), ‘Prospects of linking EU and US Emissions Trading Schemes: Comparing the Western Climate Initiative, the Waxman-Markey and the Lieberman-Warner Proposals’, *Climate Strategies*, April.

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.