Centre for Climate Change Economics and Policy

Grantham Research Institute on Climate Change and the Environment

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July 2011

Centre for Climate Change Economics and Policy Working Paper No. 62

Grantham Research Institute on Climate Change and the Environment

Working Paper No. 52

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# Climate Change and Carbon Markets: A panoramic history*

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July 2011

**Abstract**

International carbon markets have grown quickly in recent years, but have also experienced serious problems and faced harsh criticism. This paper looks at the history of climate science, at how the economics of emissions trading developed, and at the formation of international institutions to address climate change. From this historical perspective it appears that climate change was a problem in need of a solution, and that emissions trading was a solution in search of bigger and bigger problems to solve. The political pressure to reach an international climate agreement was building rapidly in the 1990s, and the resulting marriage of climate change and carbon markets occurred before the quality of the match could be adequately assessed. Many of the problems with international carbon markets can, at a fundamental level, be traced to this imperfect match. This panoramic historical perspective draws attention to the fact that climate change is a very different kind of pollution problem than emissions trading was originally designed to remedy. This helps shed light on recent experiences, and on how international carbon markets must change to provide the benefits they promise.

## 1 Introduction

The Kyoto Protocol created an international market for allowances to emit six greenhouse gases, chiefly carbon dioxide. Today, the world carbon trade includes compliance

*I owe thanks Sam Fankhauser, Carmen Marchiori for their comments on earlier drafts. I would also like to acknowledge the financial support of the ESRC and the Jan Wallander and Tom Hedelius Foundation.

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markets in the EU, the US, and New Zealand, representing over 140 billion dollars in traded value and as much as 5 gigatons of emissions per year (Linacre et al., 2011). With talk of enlarging the world carbon trade further, with proposed markets in Australia and Japan, the international market is projected to reach magnitudes of $2-3 trillion by 2020 (Lazarowicz, 2009). Despite doubts surrounding a post-Kyoto international framework, international carbon markets remain a key component of many countries' carbon policy (see, for instance, European Commission, 2011).

Yet, carbon markets have also suffered from severe growing pains. They have been criticized for not generating real emissions reductions—"hot air" in the Kyoto Protocol and overallocation of allowances in the EU Emissions Trading Scheme (EU ETS) (Reyes, 2011). They have been rebuked for providing financial windfalls to emitters—both with the admittance of HFC-23 projects into the Clean Development Mechanism (Wara, 2007a,b) and the near universal grandfathering of permits in the EU ETS (Elsworth and Worthington, 2010; Elsworth et al., 2011). They have been admonished for lacking even basic safeguards against fraud—examples include the VAT fraud and the recycling of already surrendered emissions allowances. Several national EU ETS registries were recently forced to shut down in response to one instance of theft. The international carbon markets have also been criticised for not providing the incentives for low-carbon innovation proffered by economists and politicians (Schleich and Betz, 2005).

Place this against a backdrop of economic theory emphasizing the static and dynamic efficiency of emissions trading, the lauded success of the US Acid Rain Program in the 1990s, and the acceptance of emissions trading by both business and environmental interest groups. With this background, how can we explain the recent experience with carbon markets? Are they coincidental institutional failures, or are they perhaps symptoms of a more fundamental problem?

This paper pieces together an account of the origins of international carbon markets. Accounts of the origin of international carbon markets tend to focus either on the history of climate science (Fleming, 1998; Weart, 2003), on how the economics of emissions trading developed (Oates, 2000; Gorman and Solomon, 2002; Voß, 2007), or on the formation of international institutions to address climate change (Bolin, 2007). These historical accounts are illuminating and rich in detail, but some important lessons emerge clearly only when looking at the scientific, economic, and political perspectives side-by-side (e.g. Hulme, 2009). We do this in sections 2, 3, and 4. In section 5 we examine how these perspectives became integrated and how the international carbon market was created.

A picture emerges of international carbon markets as a hasty marriage of science of climate change and economics of emissions trading, spurred on by political pressure to reach an international climate agreement. This was facilitated and encouraged by a growing scientific and popular understanding of the potential consequences of unchecked greenhouse gas emissions, and a willingness to draw very general lessons from economic arguments. To paraphrase Kingdon (1997), climate change was a problem in search of a solution, emissions trading was a solution in search of a problem, and international negotiations served as the forum in where this problem and this solution eventually came to be united.

We add detail to this sketch in section 6. The resulting picture helps us understand the troubled beginnings of international carbon markets, and suggests how carbon markets must change if they are to have hope of realising the benefits they promise.

## 2 Scientific origins

"Man is both creature and moulder of his environment"; these are the opening words of the Stockholm Declaration (1972). The idea of 'Man as moulder' is central to international climate change policy and the creation of the international carbon market. This section tells the story of how we came to understand our ability to influence the climate through our emissions of greenhouse gases.

In 1815, Jean-Pierre Perraudin speculated that large displaced boulders in the Swiss alps might be due to glaciers previously having extended farther into the valleys. 25 years later Louis Agassiz proposed the theory that prehistoric glaciers had moved across the European and North American continents. The idea was considered blasphemous at first, since it contradicted the theory that the biblical flood had displaced the boulders. However, as evidence of an ice age continued to mount, the scientific community instead became interested in explaining how temperatures could have varied enough to produce such rapid glacial advances and retreats (Riebeek, 2005).

As early as 1681, Edame Mariotte had noted that the sun's rays appeared to move more easily through glass and other transparent materials than did the rays from a heat lamp. In the 1760s and 1770s, Horace Benedict de Saussure experimented with a solar thermometer designed to capture, magnify, and measure the heat of the sun's rays (Fleming, 1998). His 'heliothermometer' was in a sense an experimental greenhouse, but Saussure did not understand the physical mechanisms that magnified the heliothermometer's internal temperature. Inspired by Saussure, however, French mathematician and physicist Joseph Fourier began exploring the 'laws' governing the transmission of heat through solids and liquids, published in his *Théorie Analytique de la Chaleur* in

1822 (Fleming, 1998).

However, Fourier's equations predicted a temperature far below the Earth's actual temperature (Weart, 2003). The problem was clear; his theory left out gases. Fourier understood that the atmosphere played an important role in regulating temperatures, famously remarking that

> ... the temperature can be augmented by the interposition of the atmosphere, because heat in the state of light finds less resistance in penetrating the air, than in repassing into the air when converted into non-luminous heat.
>
> — Fourier (1824, p. 13)[1]

Fourier experimented with the transmission of heat through transparent substances, such as panes of glass, but he was never able to extend his theory to gases.

British scientist John Tyndall had studied the radiative properties of gases early in his career, and returned to these questions once more in 1859, motivated by the mystery of the ice age. He suspected that the recent ice age might have been caused by variations in the atmosphere's carbon content (Weart, 2003). The scientific consensus of the day was that gases were transparent to thermal radiation, but Tyndall demonstrated experimentally that water vapour, carbon dioxide, ozone, hydrocarbons, and several other gases could absorb heat (Weart, 2003). He thought carbon dioxide and water vapour, absorbing many times more heat than oxygen and nitrogen, were important in explaining the Earth's temperature. Thanks to Tyndall's work, American geophysicist William Ferrel had a much better understanding than Fourier of the atmosphere's heat-trapping properties when, in 1884, he attempted to calculate the Earth's average temperature. He came much closer to reality than Fourier had ever managed (Fleming, 1998).

Fourier, Tyndall, and others had relied on experiments to formulate theories that they later tried to apply to phenomena outside of their laboratories. For Swedish electrochemist Svante Arrhenius, however, the starting point was to try to come up with a theory to fit to some poorly understood phenomena—an approach made possible in the climate sciences by the recent expansion of standardised climatological measurement. In countries around the world, geographical coverage of temperature measurements had been extended in the second half of the 19th century, and the measurement instruments and practices had been gradually standardised. The Prussian Meteorological Institute was founded in 1847, the British Meteorological Society in 1850, the US Weather Bureau in 1870, the Bureau Central Météorologique de France in 1877, and other such networks

[1]The statement was first published in 1824 in French. Quote is taken from the English translation.

formed in Italy, Russia, and elsewhere. The International Meteorological Organization (now the World Meteorological Organization) was founded in 1873 (Fleming, 1998).

Combining climatological measurements from a number of sources with well-known physical relationships, Arrhenius (1896) calculated the changes in terrestrial temperatures that would result from variation in the atmospheric concentration of carbon dioxide, taking into account the concurrent changes in humidity. A small initial decrease in temperature would lower the air's capacity to carry water vapour, which would diminish the atmosphere's heat-trapping capacity, further diminishing humidity, etc. Taking this positive feedback mechanism into account, Arrhenius found that

> the temperature in the arctic regions would rise about 8° to 9°C., if the carbonic acid increased to 2.5 or 3 times its present value. In order to get the temperature of the ice age between the 40th and 50th parallels, the carbonic acid in the air should sink to 0.62–0.55 of its present value (lowering of temperature 4°–5°).
>
> — Arrhenius (1896, p. 268)

Variations of such magnitude could explain both the warmer Tertiary and the subsequent ice age. Although it was not clear what accounted for such historical fluctuations of carbon dioxide levels, Arrhenius, quoting geologist Arvid Högbom at length, favoured the theory that volcanic eruptions might cause changes in climate. At the time, Arrhenius did not imagine that human activity could noticeably magnify the global greenhouse effect.

Industrial carbon emissions grew rapidly in subsequent years, however, and Arrhenius' collegue Nils Ekholm soon began arguing that the burning of fossil fuels would "undoubtedly cause a very obvious rise in the mean temperature of the Earth" (Ekholm, 1901, p. 61).[2] He believed, though, that the effect would only be felt over millennia. By 1904, annual industrial carbon emissions were nearly twice what they were when Arrhenius had first published. In 1906, Arrhenius wrote that "the advances of industry" might noticeably increase the atmospheric concentration of carbon dioxide "in the course of a few centuries" (Arrhenius, 1908, p. 54).[3]

But in the early 20th century, it was experimentally concluded that the heat absorption capacity of the carbon dioxide in the atmosphere was already saturated. Changes in concentration, it seemed, would have little or no effect on temperature. Arrhenius'

[2]The article was published in Swedish in 1899. The quote is taken from its English translation from 1901.

[3]Quoted from the 1908 English translation.

theories were abandoned and many climate scientists turned their attention to complementary streams of research, like mapping deep ocean currents and the carbon cycle (Fleming, 1998; Weart, 2003).

British engineer Guy Stewart Callendar went against the grain when, in 1938, he presented meticulously collated evidence that carbon dioxide emissions were causing the recent rise in temperatures. Few paid much attention (Weart, 2003), but Callendar continued to gather and analyse temperature and emissions data. Ultimately he managed to revive scientific interest in the theory among a new generation of climate scientists.

Starting in the 1940s and continuing through the 1950s, military funds were increasingly channeled into climate science, especially in the US (Weart, 2003). This new generation of climate scientists were being trained during the Second World War and the Cold War, and were highly skilled in physics and computing. They followed Callendar's lead, collecting more accurate measurements and building more sophisticated climate models. Better weather stations were built, and the first weather satellites were launched. Gilbert Plass provided new and more detailed calculations on the relationship between carbon dioxide and temperatures; Norman Philips pioneered computational climate models that have formed the basis for the general circulation models used today; Roger Revelle and Hans Seuss greatly improved our understanding the carbon dioxide absorption capacity of the oceans; Charles Keeling developed the first device able to measure atmospheric carbon dioxide levels directly from samples, and produced the famous Keeling curve from observations gathered at the Mauna Loa observatory. The era of modern climate science had begun.

## 3 Economic origins

A scientific understanding of the human-enhanced greenhouse effect is not sufficient to account for the creation of the international carbon market. Indeed, both Ekholm and Arrhenius believed that "by the influence of increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates" (Arrhenius, 1908, p. 63), even to "prevent the arrival of a new Ice Age" (Ekholm, 1901, p. 61). Callendar agreed, believing that warming would benefit humanity since "the return of deadly glaciers should be delayed indefinitely" (Callendar, 1938, p. 236). This could hardly have motivated the creation of international carbon markets.

The carbon market also reflects ideas from economics: a fear that poor management of Earth's resources might adversely affect or even limit long-term economic growth, and an understanding of how market mechanisms could be used to address externalities.

### 3.1 Growth and its limits

Since the early days of economics there has been disagreement about the sources of economic growth. Francois Quesnay and the Physiocrats, writing in the second half of the 18th century, believed land (a finite resource) was the only source of "net product" (Spengler, 1960; Fox-Genovese, 1976), an idea later developed to its logical end by Malthus (1798). Adam Smith (1776) disagreed, believing that economic growth was due to the division and specialisation of labour (Letiche, 1960; McKinley, 1960). Innovation and trade—as unlimited as human ingenuity—was the source of economic growth, which Ricardo later developed into his principle of 'comparative advantage' (Letiche, 1960). World events soon appeared to resolve this academic dispute. On the back of the rapid diffusion of the steam engine in the early 19th century, Britain grew rapidly (Fouquet and Pearson, 1998); it seemed growth would not be limited by the supply of land.

However, the broader question about dependence on finite resources would reappear again and again. Stanley Jevons (1865) argued that Britain's rapid economic growth in the first half of the 19th century could not possibly be sustained, since it relied merely on ratcheting up the rate of depletion of its coal reserves. In the 1890s, however, electricity began to replace coal as the medium for delivering power, which over time permitted a more diversified fuel mix. Coal continued to be the dominant energy source in both Britain and the US, but with the introduction of more efficient internal combustion engines, oil natural gas began to infiltrate the energy mix to a larger degree, especially in the transport sector (Fouquet and Pearson, 1998; Energy Information Administration, 2002).

Again, in the 1930s and 1940s, US dependence on imports for energy and raw materials was growing. After World War II, concerns lingered that economic growth would be vulnerable to resource prices, or that key natural resources might run out. Oil, especially, had become an important energy source, outstripping even coal by 1950 (Energy Information Administration, 2002). The Paley Commission expressed cautious concerns that the US was too reliant on oil imports (United States President's Materials Policy Commission, 1952). Hubbert (1956) formulated the influential theory of 'peak oil', predicting that both oil and natural gas production would peak around 1965-1970.

Meanwhile, two contemporaries of climate scientists Roger Revelle and Charles Keeling, Ewing and Donn (1956), published an article arguing that if the Arctic ice sheet gave way to open ocean, snowfall would increase at high latitudes, triggering glacial advance and global cooling. Declining temperatures in the 1950s and 1960s seemed to be evidence that global cooling was already underway (Fleming, 1998). These global cooling fears were compounded by other scientific discoveries in the 1960s showing the cooling effects of aerosol pollution. The prospect of global cooling engendered grave concerns about food production, conflict, and mass migration (Fleming, 1998). This reaction may have been in part due to the political climate of the Cold War. Nevertheless, for the first time reports were written on the dangers of anthropogenic greenhouse gas emissions. The US President's Science Advisory Committee (1965), for instance, issued a warning of the dangers of anthropogenic climate change. They argued that emissions would cause climate change, but did not specify whether there would be warming or cooling.

Whether the Earth was warming or cooling, it quickly became clear that economists they were ill-equipped to analyse the economic implications of climate change. They had debated the growth implications of natural resource dependence for centuries, but the focus had been on more traditional natural resources (e.g. coal and oil), largely overlooking society's dependence on ecosystem services (e.g. the atmosphere and oceans as pollution sinks). Perhaps pollution, rather than exhaustion, would provide the ultimate constraint on economic growth? One metaphor reflected this shift in economic thinking—'Spaceship Earth' (Boulding, 1965, 1966; Ward, 1966).

> As long as man was small in numbers and limited in technology, he could realistically regard the earth as an infinite reservoir, and infinite source of inputs and an infinite cesspool for outputs. Today we can no longer make this assumption. Earth has become a space ship...In a space ship there are no sewers.
>
> —Boulding (1965, p. 1)

In this spirit, the Club of Rome embarked on a major interdisciplinary effort to investigate "the predicament of mankind". Their first report predicted that known reserves of oil and natural gas would be exhausted by the early 1990s, that coal reserves would be depleted sometime in the second half of the 21st century, and a number of other metals and minerals would run out soon. It also predicted that "industrial growth will certainly stop within the next century, at the latest" (Meadows et al., 1972, p. 126).

Economists Robert Solow (1973) retorted that a constant level of consumption was even achievable in an economy *perpetually dependent* on a finite resource, even without technological progress.[4] But the Club of Rome left a much more important legacy than

[4]Solow's updated version of Trevor Swan's growth model would perhaps rank as his better known contribution to the theory of economic growth. This, however, is an infinite-resource model, and will not be discussed here.

its predictions about the more traditional natural resources, which had been the main focus of Solow's criticism. They had emphasised the complex web of economy-environment interactions, and their model included elements of both pollution and exhaustion—perhaps the world's first integrated assessment model.

This debate underlined the difference between dependence on traditional natural resources, which could be managed by relatively well-functioning markets, and dependence on ecosystem services, for which markets did not exist. Economists still had little to say about the growth prospects for an economy dependent on ecosystem services, and now anthropogenic global warming was an example where ecosystem dependence might be put to the test. The relationship between economic growth and the greenhouse effect was clearly in need of further examination.

Economist William Nordhaus (1974) addressed the issue head on, arguing that unacceptable human enhancement of the greenhouse effect may constrain economic growth before the physical scarcity of energy resources ever would become a problem. His writings began to shift the debate from exhaustion to pollution, and climate change was now finally beginning to be acknowledged and examined as a major concern for economic growth. Scientists had learnt a lot about the physical mechanisms, and economists now better understood the potential economic implications. All appeared to agree about the magnitude of the problem, but what could be done to fix it?

### 3.2 Markets for pollution

Adam Smith recognised the problem presented by externalities, and argued that the government should step in to resolve such failures of coordination (Smith, 1776, p. 690). John Stuart Mill, recognised the same problem, but was not as eager to proclaim government as the solution. Mill argued for an economic test to determine the limits of government intervention, but was never able to develop such a test (Medema, 2003). Henry Sidgwick (1883) went even further in trying to explain the origin of this discrepancy between private and social interests, and Sidgwick even married the idea of externalities with the climate in one of his examples. He wrote that "if it is economically advantageous to a nation to keep up forests, on account of their beneficial effects in moderating and equalizing rainfall, the advantage is one which private enterprise has no tendency to provide; since no one could appropriate and sell improvements in climate" (p. 413). Thus, if the government could be trusted, it could act on behalf of the public interest when markets failed.

Alfred Marshall began thinking about using economic incentives instead. At a hearing for the Royal Commission on Labour, during a discussion about the growth of cities, Marshall asks if the witness is aware of proposals "that every person putting up a house in a district that has got as closely populated as is good, should be compelled to contribute towards providing free playgrounds?" (Royal Commission on Labour, 1893, p. 611).[5] Marshall's star pupil, Arthur Pigou (1912), delved deeper into the subject, and, quoting Marshall (above), argued that "the principle [was] obviously susceptible of general application" (p. 164).

Pigou discussed examples like street lights, light-houses, and especially smoke pollution.[6] Smoke pollution was such a clear and easy-to-relate-to example of externalities at the time, but unfortunately also seemed to communicate that externalities were largely 'nuisance' problems of no great macroeconomic significance. This can be contrasted with Sidgwick's earlier examples, where externalities could even change the climate.

Ronald Coase (1959, 1960) continued the focus on 'nuisance' problems like feuds between neighbours, but broke with Pigou in one important respect. He criticised "economists who, following Pigou, approach the problem [of social cost] in terms of a difference between private and social products but fail to make clear that the suppression of the harm which A inflicts on B inevitably inflicts harm on A". "The reciprocal nature of the relationship", he wrote, "tends to be ignored". Reciprocity implies that, "once the legal rights of the parties are established, negotiation is possible" (p. 26). "The delimitation of rights is an essential prelude to market transaction" (p. 27), and thus, "it can be left to market transactions to bring an optimum utilization of rights", however those rights are initially allocated.

The problem with tradeable rights was transactions costs. On the problem of smoke pollution, Coase wrote that

> ... if many people are harmed and there are several sources of pollution, it is more difficult to reach a satisfactory solution through the market. When the transfer of rights has to come about as a result of market transactions carried out between large numbers of people or organizations acting jointly,

[5] Marshall's academic work on 'external economies and diseconomies' considered a wholly different set of economic questions. He wondered if externalities could explain the development and agglomeration of industry.

[6] As an interesting side note, the focus on smoke pollution was likely due to the growing problem of smoke pollution in British cities at the time. Ever since more efficient chimneys had been introduced in the 15th century, individuals were able to externalise smoke pollution (Brimblecombe, 1987). By the 19th century, rapid urbanisation and Britain's growing use of coal, in combination with inefficient stoves and iron smelting practices produced considerable smoke in British cities. Emissions rose rapidly throughout the 1800s, and London was becoming known as one of the most polluted cities in the world (Brimblecombe, 1977; Fouquet and Pearson, 1998).

> the process of negotiation may be so difficult and time-consuming as to make such transfers a practical impossibility... As a practical matter, the market may become too costly to operate.

He continues to say that

> In these circumstances it may be preferable to impose special regulations... Thus the problem of smoke pollution may be dealt with by regulations which specify the kind of heating and power equipment which can be used in houses and factories or which confine manufacturing establishments to certain districts by zoning arrangements.

—Coase (1959, p. 29)

Coase, it seems, thought emissions trading was a bad idea. Thomas Crocker (1966), however, argued that there were important advantages in using a system of tradeable permits for air pollution, because it allowed the regulator to learn from the price signal. John Dales (1968a,b) believed that, with taxes or subsidies, "all dischargers would reduce their wastes up to the point where the marginal cost of doing so equalled the subsidy provided, or the charge levied" (Dales, 1968a, p. 800), but that it would be incredibly difficult to set and continually adjust taxes to achieve the desired environmental quality. In the context of water pollution, he thought that a better alternative was to

> Let [the government]... issue $x$ pollution rights and put them up for sale, simultaneously passing a law that everyone who discharges one equivalent ton of waste into the natural water system during a year must hold one pollution right throughout the year... The virtues of the market mechanism are that no person, or agency, has to *set* the price—it is set by the competition among buyers and seller of rights...

—Dales (1968a, p. 801)

In subsequent years Baumol and Oates (1971) formally demonstrated the least-cost property of environmental taxes, and Montgomery (1972) did the same with emissions trading. Weitzman (1974) in fact showed that "[i]n an environment of complete knowledge and perfect certainty, there is a formal identity between the use of prices and quantities as planning instruments. If there is any advantage to employing price or quantity control modes, therefore, it must be due to inadequate information or uncertainty" (p. 480). In such a world, "neither instrument yields an optimum *ex post.* The relevant question is which one comes closer under what circumstances." (p. 482). The instrument choice debate flourished, with important early contributions from Roberts and Spence (1976), Adar and Griffin (1976), Yohe (1977), and Baumol and Oates (1979). The theory of emissions trading was becoming better understood, but it was still largely focused on local pollution problems. Emissions trading could perhaps remedy such 'nuisance' problems, but no one was proposing to use it to tackle climate change.

# 4 Political origins

Even though climate scientists had appreciated that greenhouse gas emissions would impact the Earth's climate since the turn of the century, in the political arena, air pollution was still considered an essentially local problem even through the 1960s. When the US National Air Pollution Control Administration compared the cost-effectiveness of alternative pollution abatement strategies, they did so on a city-by-city basis (Burton and Sanjour, 1968, 1969a,b).

The environmental movement in the US had been growing in the 1950s and 1960s, but the prevailing view, especially among businesses, was that restraining pollution would act as a 'growth-ban' (Cook, 1988). The academic work of Coase, Crocker, and Dales provided an innovative solution to local pollution problems that might satisfy both environmentalists and businesses: a cap on pollution, but flexibility in how to achieve that target. Burton's and Sanjour's analyses began looking at the possibilities for using market-based instruments, like emissions trading. The US Environmental Protection Agency (EPA), established in 1970 under the Republican President Richard Nixon, soon began experimenting with such 'flexible regulations'. The EPA began allowing some firms to transfer their emissions quotas internally between its facilities, as if the firm existed under a 'bubble'. Before long it extended the principle to allow transfers between firms, creating the 'offset mechanism' (Voß, 2007). Offsets received official sanction through the 1977 amendments to the *Clean Air Act*.

The EPA continued to experiment with and expand the use of market-based instruments under both the Carter and Reagan administrations, introducing, for instance, 'emission reduction units' as a currency for compliance (Voß, 2007), as well as 'netting' and 'banking' of these units (Gorman and Solomon, 2002). In the late 1970s, as leaded petrol was being phased down in the US, a refinery that could not meet its target lead-content could secure the right be *averaged* with a refinery that went beyond its target. Both refineries were considered in compliance as long as the average lead-content of petrol met the overall target (Gorman and Solomon, 2002).

In 1982, the EPA presented an *Emissions Trading Policy Statement* consolidating these new practices (although final publication was delayed until 1986). In 1985, Tietenberg (1985) published a study evaluating the EPA's *de facto* emissions trading system. He "pulled the nascent policy scheme out from the shadow of the command-and-control regime and highlighted it as a first instance of a new policy instrument in practice, a proof of the principle that emission reduction obligations could be traded" (Voß, 2007, p. 334).

Tietenberg's report was significant, also, because alongside the standard argument of static production efficiency, which had so often been used in favour of emissions trading, he argued that emissions trading provided the right incentives for innovation and investment in pollution control. Kneese and Schultze (1975) had formulated the influential view that:

> Over the long haul, perhaps the most important single criterion on which to judge environmental policies is the extent to which they spur new technology toward the efficient conservation of the environment.
>
> —Kneese and Schultze (1975, p. 38)

The need for innovation and investment incentives in pollution control was now increasingly recognised. Downing and White (1986) argued in favour of emissions trading on this basis. The economic arguments about static and dynamic efficiency slowly began to gain favour, and advocacy for emissions trading in the US soon spread beyond the EPA to groups like Project 88 and the Environmental Defense Fund. The shift in attitude in the 1980s towards more flexible environmental regulations was also greatly facilitated and encouraged by the broader push for neoliberal economic policies that was taking place under the stewardship of the Reagan administration.

On a largely parallel political track, two pollution problems were increasingly recognised to be international in reach, rather than local: (1) sulphur dioxide emissions from burning coal and oil was causing water acidification, and (2) emissions of chlorofluorocarbons depleted stratospheric ozone (Bolin, 2007). In response to growing concerns about water acidification, the U.N. convened the Conference on the Human Environment in June 1972, producing the Stockholm Declaration (Bolin, 2007). A few years later, the Final Act of the Conference on Security and Co-operation in Europe in 1975 set out, among the aims for future co-operation, the "desulphurization of fossil fuels and exhaust gases, pollution control of heavy metals, particles, aerosols, nitrogen oxides, in particular those emitted by transport, power stations, and other industrial plants", agreeing, as a specific measure, to "develop through international co-operation an extensive programme for the monitoring and evaluation of the long-range transport of air pollutants, starting with sulphur dioxide". The Convention on Long-Range Transboundary Air Pollution in

1979 was more aggressively worded, but did not mandate any emission reduction targets. When binding emissions reductions finally made it into the Helsinki Protocol in 1985, it mandated uniform 30% reductions of sulphur emissions by 1993, against 1980 levels. Economic principles are conspicuously absent from such a solution, but at least it recognised some pollution problems went beyond local, or even national regulation.

On the issue of ozone depletion, a voluntary international agreement in 1978 to reduce chlorofluorocarbons emissions was followed by The Vienna Convention for the Protection of the Ozone Layer in 1985. In 1987, two years after British scientists had discovered a marked thinning of the ozone layer over the Antarctic, the Montreal Protocol was agreed. It added binding emissions reduction targets to the Vienna Convention, but perhaps more notably, it included a provision to allow countries to transfer parts of their emissions quotas to other nations. The ideas that the EPA had been experimenting with on a much smaller scale were suddenly launched onto the international stage.

However, in practice, the quotas were strict, the emitters were few, and no accounting procedures were included in the Protocol. As a consequence, the trading provisions were rarely exercised (Gorman and Solomon, 2002). Although emissions did decline, there was virtually no trading under the Montreal Protocol itself. International emissions trading had not succeeded.

The Montreal Protocol did, nevertheless, provide the impetus for a compliance market in the US. In 1988, the EPA instituted a regime for Protection of Stratospheric Ozone, capping production of chlorofluorocarbons through a tradeable permit system (Tripp and Dudek, 1989). The success of this program, combined with the growing support for emissions trading in the US, allowed George H.W. Bush to amend the *Clean Air Act* in 1990. This created the US Acid Rain Program—a national permit market for sulphur dioxide emissions. This scheme was later praised for achieving substantial emissions reductions at a much lower cost than expected. It has since been held up as a shining example of the potential benefits of emissions trading.

## 5 Carbon markets: A marriage of science, economics, and politics

Since the days of Pigou, externalities had been viewed largely as 'nuisance' problems. Even as the US environmental movement was growing in the 1950s and 1960s, the prevailing view was still that environmental regulation would act as a 'growth-ban' (Cook, 1988). Environmental regulations were pursued largely in the spirit of consumer protection. The 1954 International Convention for the Prevention of Pollution of the Sea by Oil, for instance, was prompted by specific oil spills that caused damage to people, property, and the marine environment. The European Community's first environmental resolution from 1967 aimed to regulate product packaging and labeling (Sands, 2003). Pollution was certainly a 'nuisance', but it was not a serious economic threat.

This view slowly began to change in the 1970s and 1980s, however. Climate scientists continued to accumulate evidence of global warming, and economist William Nordhaus (1974, 1977a,b, 1979) warned of the potential economic consequences of global warming. He described greenhouse gas emissions as "a pure example of an externality" Nordhaus (1977a, p. 19), calling it "the most extreme imaginable form of external diseconomy" (Nordhaus, 1977b, p. 342).

In 1987, the U.N. World Commission on Environment and Development published their report on Our Common Future (World Commission On Environment and Development, 1987). Global warming, and the necessity of managing climate change, was clearly recognised. Highlighting problems of over-exploitation of environmental resources, the report defined a new political agenda around the concept of 'sustainable development'. It recognised that our economic future was fused to our ability to manage global common-pool natural resources, such as the atmosphere.

In 1988, a hot summer and crop failure in the US sparked a wider political discussions about anthropogenic global warming. NASA scientist James Hansen testified before the US Congress, declaring that "global warming has begun", a statement that echoed around the world (Fleming, 1998; Bolin, 2007). The World Conference on the Changing Atmosphere held that same year called for a 20% reduction of carbon dioxide emissions by 2005, against 1988 levels. Later that year, the Intergovernmental Panel on Climate Change (IPCC) was created to conduct a comprehensive scientific assessment of the causes and consequences of global warming. An externality like excess greenhouse gas emissions, it was now abundantly clear, was much more than just a 'nuisance'. If unchecked, it could pose a serious economic threat.

Putting the problem of climate change together with the theory of emissions trading, Swisher and Masters (1989) argued that we should use an "international market mechanism that assigns value to climate protection", using "international carbon emissions offsets" as currency. The US filed a concept paper with a similar proposal to the IPCC the same year, and Victor (1991) argued that it was feasible to implement such a scheme to manage carbon dioxide emissions. Dudek and LeBanc (1990) of the Environmental Defense Fund proposed even broader offsetting mechanisms that would include forestry offsets.

The UN convened the Conference on Environment and Development in Rio de Janeiro in 1992, producing the Framework Convention on Climate Change (United Nations, 1992). Its 156 signatories declared their "concern that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases... and may adversely affect natural ecosystems and humankind". The Convention established an international framework within which it would be possible to limit anthropogenic greenhouse gas emissions. It also demanded that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost". This was a clarion call for economists.

Many economists turned their attention to questions of formulating an international environmental treaty and designing an international market for greenhouse gases. Michael Grubb, Peter Bohm, Scott Barrett, Graciella Chichilnisky, Richard Sandor and many others made important contributions to the growing debate.[7] By 1992, both the UNCTAD and OECD had already presented their own analyses of a possible international system of tradeable carbon emissions permits. When the IPCC completed their second assessment report in 1995, it included a working group dedicated to examining the economic and social dimensions of climate change. They concluded that "for a global treaty, a tradeable quota system is the only potentially cost-effective arrangement where an agreed level of emissions is attained with certainty" (p. 401).

The recommendation rested on the standard arguments in favour of emissions trading, similar to those heard decades earlier in the discussion about local and national emissions regulation in the US; not only would an international carbon market achieve the target emissions reductions with certainty, but it would do so in a statically and dynamically efficient manner. That same year, in 1995, the UNFCCC launched a voluntary pilot market, Activities Implemented Jointly (AIJ), to learn more about how an international carbon market might work in practice.

The US initially opposed binding commitments in the lead up the Kyoto negotiations, but their position shifted after the second assessment report was released. It now favoured binding commitments as long as the new agreement included provisions for an international carbon market. The US was one of the few countries with practical experience of emissions trading, but an alliance including the US, Australia, Canada, Iceland, Japan, New Zealand, Norway and Russia quickly formed around the proposal for international carbon emissions trading (Stowell, 2005). The Kyoto Protocol was agreed in

[7] For a more comprehensive list of references to relevant papers in this period, see the bibliography of chapter 11 of the Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change (Bruce et al., 1996).

1997, and established an global market for greenhouse gas emissions reductions.

Since 1997, a number of emissions trading systems have been implemented across the globe, and the political landscape of proponents and skeptics of emissions trading has changed. The 'flexible mechanisms' of Kyoto went into operation in 2005, together with compliance markets such as the EU Emissions Trading Scheme, and much has been learnt about from these experiences.[8] But the fact remains: in less than a decade, international carbon markets had gone from being an academic idea (Swisher and Masters, 1989) to being a central component of international climate policy.

## 6 Taking stock and looking forward

Climate scientists understood the anthropogenic global warming posed a grave threat, but also that this problem was not merely a scaled up version of air pollution. In fact, the study of climate change arose from the a wholly different branch of the physical sciences: the study of the ice ages and fluctuations of terrestrial temperatures. Climate scientists were concerned with the dynamic behaviour of a global system. The climate system was full of positive and negative feedback mechanisms, and could respond in complex ways to anthropogenic greenhouse gas emissions. Economists, however, were offering a scaled up version of the solution to air pollution.

The arguments in favour of emissions trading had been its ability to cap emissions at a desired level, to achieve abatement at the lowest overall cost, and to provide the right incentives for firms to innovate in environmentally friendly technologies. The same arguments were now put forth to support the recommendation of an international carbon market. After all, schemes like the US Acid Rain Program were proof that this was not only theory, but really did work in practice. Things were moving very quickly in the early 1990s. Climate change was a problem in search of a solution, and emissions trading was a solution in search of a problem. Despite the failure of the one truly international emissions trading scheme that had existed up to this point under the Montreal Protocol, politicians, rushing take action against the climatic threat, were willing to buy this solution if it meant getting the US on board.

From this perspective, many of the problems that international carbon markets have experienced in recent years are easier to understand. While local and national trading schemes had institutions in place for allocating emissions rights, the "hot air" in the Kyoto Protocol and overallocation of allowances in the EU Emissions Trading Scheme (EU

[8]To read more about post-1997 developments, see Stowell (2005), Voß (2007), Bolin (2007), Brohé et al. (2009), and Ellerman et al. (2010).

ETS) (Reyes, 2011) are symptoms of the absence of comparable international mechanisms. The VAT fraud and the recycling of already surrendered emissions allowances are similarly symptoms of the much more underdeveloped area of international law enforcement. While local and national trading schemes had dealt with a very limited number of pollutants and where the key abatement technologies were all known in advance, the admission of HFC-23 projects into the Clean Development Mechanism (Wara, 2007a,b) is a symptom of the much more inadequate understanding of the abatement options for greenhouse gases. In light of all these institutional failures, it would perhaps not be a surprise to anyone if the international carbon markets have not provided the strong long-term price signal needed to incentivise low-carbon innovation.

The historical perspective helps us understand why international carbon markets so far have failed in several important respects, but also helps us understand how carbon markets must change if they are to have hope of realising the benefits they promise. I will suggest two main conclusions.

Firstly, while emissions trading was first developed to deal with more or less localised air and water pollution, the science of anthropogenic global warming did not emerge as a scaled up version of local air or water pollution. The original problem was to explain terrestrial temperatures. The climate system is associated with a much higher degree of scientific uncertainty than systems dealt with by previous emissions trading regimes, and exhibits very different dynamic properties. Experiences with international carbon markets suggest that all of the incongruences between the climate science and the theory of emissions trading have not been ironed out yet, so it is important not to let emissions trading be the be-all and end-all of carbon policy. Rather, it can be a part of a carbon policy portfolio, which has room for back-up options, like geo-engineering, that are better suited to dealing with the kinds of catastrophic climate risks that emissions trading was never intended to address in the first place.

Secondly, an unreasonable degree of institutional homogeneity and low transactions costs was implicit when the small-scale theory and experience of emissions trading was applied on a global scale. The instrument choice debate had long recognised that the costs of operating any particular combination of policy instruments in a given environment is crucial in determining the optimal instrument mix. Weitzman readily admitted that his analysis did not go nearly far enough in accounting for administrative and other operational costs (Weitzman, 1974, p. 481). There is a small literature on conducting environmental policy in the presence of administrative costs (Mitchell Polinsky and Shavell, 1982; Stavins, 1995; Woerdman, 2001), but it needs to be expanded and integrated into analysis of the global carbon market. This will inform policy makers of the appropriate role of international carbon markets within a broader portfolio of policies. It can help make sure that international carbon policies are complementary, and that markets are used only to address that part of the problem for which they are most effective.

More a historical observation than a lesson, it is perhaps encouraging to note that while externalities were for a long time considered 'nuisances', regulated mainly to protect consumers, greenhouse gas emissions are now widely recognised as a threat to economic growth. Climate change regulations are still viewed as a 'growth-ban' in several countries, but the trend is towards recognising climate change itself is the greater threat.

International carbon markets combines climate science, the economics of emissions trading, and the international treaty making. A panoramic historical perspective suggests the combination is better described as a hasty marriage than a carefully engineered synthesis. The many problems with international carbon markets appear to have resulted from incongruences between the contributions made from each camp. Carbon markets are likely to continue playing an important role in international carbon policy, and practical experience with carbon markets continues to provide information for researchers and policy makers about the nature of remaining incongruences. Future efforts should go beyond the surface and focus more on understanding the more fundamental restrictions on the ability of international carbon markets to address climate change. This will help ensure that carbon markets are given an appropriate role in climate policy. Only then will international carbon markets be able to realise the benefits they promise.

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