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Article

New and old market-based instruments for climate change policy

Sebastian R. Goers[1], **Alexander F. Wagner**[1,2], **and Jürgen Wegmayr**[3]

[1] Energieinstitut at the University of Linz, Altenberger Strasse 69, A-4040 Linz Auhof, Austria
[2] Swiss Finance Institute, University of Zurich, Plattenstrasse 14, CH-8032 Zurich, Switzerland
[3] Energie AG Oberösterreich Trading GmbH, Böhmerwaldstrasse 3, A-4020 Linz, Austria

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Abstract We review and examine three market-based instruments to address the challenge of climate change: emission trading, emission taxes, and hybrid instruments. Our main contribution is the illustration and comparison of these instruments using recent results from theoretical research and practical policy experience. Hybrid policies that aim to combine taxes and permits emerge as a promising way forward. An additional contribution is that we also comment on two other related concepts, namely, innovation strategies and prediction markets. For the former, we show that, to make economic sense, the much publicized Asia-Pacific Partnership on Clean Development and Climate has to rely on the same basic tool as the other instruments, namely, relative prices. For the latter, we discuss how prediction markets can complement traditional scenario analysis by experts. They are likely to improve the practical implementation of all previously discussed methods.

Key words Climate change · Market-based policies · Prediction markets · Tradable permits · Emission taxes

1 Introduction

Unabated climate change threatens to fundamentally change and indeed worsen quality of life on this planet. Measurements of global temperature show that the average temperature has augmented by about 0.74°C in the past 100 years, while the number and the frequency of extreme weather events like heat waves, meagerness, strong rainfalls, and tropical storms have increased. For a scenario of no mitigation of greenhouse gas (GHG) emissions, the increase of the global average temperature is estimated to be around 0.2°C per decade (Intergovernmental Panel on Climate Change 2007). In November 2006, the *Stern Review* (Stern 2006) presented a dramatic scenario that could occur if nothing changes in the context of climate protection. The concentration of GHG in the atmosphere is about 430 parts per million (ppm) carbon dioxide (CO_2), compared with 280 ppm CO_2 before the Industrial Revolution. This concentration leads to an increase of global temperature by more than 0.5°C and will lead to a further increase of at least 0.5°C over the next few decades. If annual emissions do not increase above today's rate the GHG concentration will reach 550 ppm, which will probably lead to an increase in global temperature of more than 2°C (Stern 2006). To stabilize the GHG concentration at 550 ppm, global emissions will have to decrease by about 25% below today's level. For a stabilization at 450 ppm, the decrease will have to be 70% until the year 2050 (Stern 2006).[1] Similarly, the Intergovernmental Panel on Climate Change (IPCC) predicts scenarios of a slow increase in globally averaged surface temperature between 1.1° and 2.9°C and scenarios of an extreme increase between 2.4° and 6.4°C for the twenty-first century (IPCC 2007). Stabilization of the GHG in the atmosphere between 445 and 535 ppm CO_2 in 2030 would cost maximally about 3% of the global gross national product (GNP). In the third IPCC assessment report, an increase of global temperature by 1°C was equated with a global loss of about US $214 trillion over the next 50 years. In the year 2050 alone, damages of about US $2 trillion have to be expected (IPCC 2001).[2] Of course, there is great uncertainty attached to these estimates, but Weitzman (2009) shows that the economic consequences of fat-tailed structural uncertainty (along with uncertainty about high-temperature damage) can readily outweigh the effects of discounting in climate change policy analysis, thus calling for urgent action.

Because of the importance of the problem, much literature has dealt with optimal ways to address climate change with economic tools. It has long been recognized that command and control instruments (like fixed standards over inputs, outputs, or technologies, or location controls) are inadequate to obtain the desired reduction of emissions in cost-minimizing ways. Therefore, we focus on market-based instruments that hold the promise of cost effectiveness.

This article reviews and investigates the theoretical setup and practical workings of three different possible actions against climate change, and reveals the operating experience. The main contribution of the article is that it reviews, following the same criteria for all instruments, and draws on the most recent available findings for all three of these basic instruments. While some reviews of individual systems are available, there exists, at least to our knowledge, no current article that compares all three systems. Such a comparison is important because in using a partial approach it is relatively easy to critique (or favor) one system

[1] For a critical discussion of the *Stern Report* concerning issues of the rate of discount and cost–benefit analysis, see Tol (2006) and Nordhaus (2006).

[2] Although climate change is a global problem, its impacts are often best appreciated by policymakers and citizens alike when broken down into effects for their own country. To illustrate the impact of climate change in Europe to readers in Asia, some results for Austria and Germany shall be considered by way of example: Vienna is faced with a doubling of the number of days with the maximum temperature exceeding 30°C within the next 50 years. The frequency of high maximum temperatures has increased in Vienna in the period of 1951–2000 over that for the period 1901–1950. The Schmittenhöhe (a well-known ski area), on the other hand, is faced with a reduction of days with maximum temperatures below 0°C by one third (Kromp-Kolb 2003). Numbers for Germany show that the increasing numbers of natural disasters will lead to damages of about 137 billion Euros until the year 2050 (Kemfert and Praetorius 2005). A study by the ETH Zurich and Swiss Re found that the damages through winter storms in Europe will increase until 2085 up to 68% from 1975 values (SwissRe 2006).

not keeping in mind that it may dominate (or be dominated by) other systems on another dimension. We study tradable permits, emission taxes (and subsidies), and a hybrid between permits and taxes. We cover the basic workings of emission trading and emission taxes (subsidies for reductions) only rather briefly because a lot of literature is available on them. The third instrument—less known in Europe but important in the policy discussion in the US—is a hybrid instrument that combines trade and tax systems to optimize the advantages the two former systems have. The recent experience in Europe is of significant interest for Asian economies. We argue that the European Emission Trading System (ETS) has likely failed in achieving efficiency in its first phase because too many permits were allocated for free. This resulted in excessive emissions in the ETS sector and produced an additional burden to mitigate pollution in the non-ETS sector. It may also have led to a lack of incentive to engage in emissions trading on the firm level. Hybrid policies are likely to be attractive for future policy adjustments because they allow scarce initial allocations of permits while still giving sufficient safety to industry, should abatement costs turn out to be unexpectedly high.

Our second contribution is that we challenge a much-publicized approach focusing on technological progress. The governments of Australia, Canada, China, India, Japan, South Korea, and the USA are in favor of this approach as a complement to the Kyoto Protocol. They have documented their preference for this approach recently through the founding of the Asia-Pacific Partnership on Clean Development and Climate (APP). Because of the dual characteristics of this strategy—technological progress and international diffusion—we refer to this approach as the innovation and cooperation strategy.[3] Little specific information is available yet on this partnership, and it is to some extent still obscure exactly what the operational approach will be. What is clear after our analysis, however, is that this approach, too, will have to rely on a working price system.

Because all policy tools are strongly affected by uncertainty and difficulties to predict future outcomes, we also propose to establish a "prediction market" for future technologies. On such a market, claims on the likelihood of various technological innovations are traded, thus using the aggregate knowledge of all market participants in addition to relying on estimates of policymakers or a few experts.

We begin in Sect. 2 with an explanation and evaluation of the different economic instruments that support the fight against climate change. The emphasis here is on efficiency and effectiveness. Section 3 takes account of the instruments with respect to several additional important dimensions, including ecological effectiveness and political feasibility. In Sect. 4, we focus on the issue of uncertainty and propose prediction markets as an effective complement to existing ways of forecasting the future. Section 5 concludes.

[3] There are other instruments that we do not discuss. Perhaps the biggest omission is that we do not deal with carbon sequestration and reforestation. We refer the reader to Lecocq and Chomitz (2001), Lubowski et al. (2006), Stavins (1999), and Stavins and Richards (2005).

2 Overview of market-based methods to fight climate change

In contrast to many textbooks and general surveys, we especially direct our attention to issues relevant to Europe in order to see how the policies implemented fit with the recommendations of economic theory; this in turn can then enrich our discussion of policy not only for Europe but also for other countries, including countries in Asia. Because of the prominence of the debate in the USA, but not in Europe and in Asia, we spend considerable time laying out the operation mode and crucial issues of implementation of a hybrid policy. At the end of the section, we discuss a strategy that focuses on innovation and cooperation. Although this strategy is advertised as a new approach by the APP, at least from the currently available documentation of that partnership, the strategy appears to be consistent with and indeed a logical corollary of the other three approaches.

2.1 Emission trading

Emission trading is one of the flexible mechanisms of the Kyoto Protocol and shall therefore play an important role in reaching international climate targets. The Kyoto Protocol's provision for an international cap-and-trade system paves the way for the implementation of the regional emission trading system in Europe (Stavins 2008). One important point why emission trading was chosen to help reach the Kyoto targets is that, like taxes, it allows emissions to be reduced where it is cheapest for the economy, that is, it is cost effective (Dales 1968; Montgomery 1972). In a framework where permits are allocated for free, an emission trading system does not involve transfers from the private sector to the government vis-à-vis an emission tax approach.

The basic setup is that a regulator sets an emission cap for a certain sector. The level of this cap depends on the target that should be achieved. The more ambitious the target, the lower the overall cap is. When the overall cap is set, each participant (the individual firms) will get a certain allocation of emission allowances. This allocation can happen in two different ways. The first, which is used in the European Union (EU) ETS, is "grandfathering." With this method, emission rights are mainly allocated according to the past emissions of each company. The alternative is to auction off allowances. We discuss these two approaches below.

In general, the EU ETS covers installations such as combustion plants, oil refineries, coke ovens, iron and steels plants, and factories producing cement, glass, lime, brick, ceramics, and pulp and paper. Sectors or industries that are not covered by the scheme, such as the private sector, transport, or the building industry, have to be regulated by other (national) abatement measures in order to reach each national emission reduction target. To illustrate the quantities involved, Table 1 shows the allocated emission allowances of some large European companies. It becomes clear that because of the size of the market, even a low or moderate price of allowances is substantial, as is the potential cost for each individual company.

Table 1. Emission allowances allocated to some European companies

Sector	Company	Allocated allowances (1000 tons CO_2) 2005–2007	Allocated allowances (1000 tons CO_2) 2008–2012	National Allocation Plan
Steel	ThyssenKrupp Stahl AG	48 190	98 552	Germany
	Voestalpine	34 069	56 710	Austria
Electricity	EnBW Kraftwerke AG	30 237	33 880	Germany
	Vattenfall Europe Generation AG & Co. KG	198 607	187 887	Germany
	Verbund	10 033	12 519	Austria
	EdF	64 535	80 835	France
Refinery	OMV	8303	14 960	Austria
	Shell	10 616	25 131	UK
	BP	11 582	25 103	UK
	Esso	10 871	16 591	UK

Source: National Allocation Plans of the different countries

Table 2. CO_2 emissions of different regions (in million tons)

Year	World	EU-15	EU-27	China	India	Japan	South Korea
1995	23 108	3277	4141	3013	916	1305	374
1996	23 903	3355	4242	3216	999	1328	408
1997	24 118	3301	4154	3157	1042	1322	424
1998	24 905	3347	4142	3022	1070	1287	364
1999	24 083	3321	4076	2735	1140	1318	396
2000	24 677	3349	4100	2740	1155	1344	431
2001	24 918	3418	4179	2800	1181	1341	438
2002	25 874	3409	4155	3532	1226	1328	446
2003	27 020	3488	4263	4146	1264	1376	454
2004	28 424	3508	4283	4881	1343	1391	466
2005	29 430	3486	4258	5380	NA	1401	NA
2006	30 047	3466	4258	5944	NA	1381	NA
2007	30 892	NA	NA	6389	NA	1393	NA

Source: Eurostat, Internationales Wirtschaftsforum Regenerative Energien, Umweltbundesamt, United Nations Statistics Division
NA, not available

To put the role of the emission trading program into perspective with the overall amount of emissions, it is instructive to consider the overall amount of CO_2 emissions, which are shown in Table 2. Emission trading in the European Union only covers a part of these emissions. In the EU ETS, emission allowances for approximately 2.2 billion tons of CO_2 were allocated per year for the period 2005–2007. For 2008–2012, emission allowances for approximately 1.9 billion tons of CO_2 have been allocated per year without accounting for changes in the captured installations and sectors by the scheme.

The second way to allocate the allowances is via complete or partial auctioning. Companies bid for the amount of emissions they would probably need and have to buy the certificates. This is generally seen as the preferred way of doing the allocation.[4] First, auctions are more cost effective in the presence of certain kinds of transaction costs. Second, the revenue raised can be used to reduce other distortions. Note also that instruments such as tradable permits can create entry barriers that raise product prices, reduce the real wage, and exacerbate preexisting labor supply distortions. This effect can be offset if the government auctions the permits, retains the scarcity rents, and recycles the revenue by reducing preexisting distortionary taxes (Goulder and Bovenberg 1996).[5] Third, auctions provide greater incentives for firms to develop substitutes for CO_2-intensive technologies. Fourth, due to the revenue raised by auctions, administrative agencies may have a bigger incentive to monitor compliance (Ackermann and Stewart 1985). Finally, grandfathering can lead unregulated firms to increase their emissions in order to maximize the pollution rights that they obtain if there is a transition to a market-based system (Dewees 1983). For all these reasons, an auction of emission rights may be preferable to grandfathering, which could lead to the conclusion that the EU ETS is likely to be highly inefficient currently on this dimension.

In practice, and taking into account the political process, the auctioning of permits may not be preferred to grandfathering. One common assumption is that the regulated industries would oppose auctioning. But this is not the only possibility. For example, Lai (2008) considers the lobbying behavior of interest groups and shows that industrial lobbies may endorse an auction while environmental lobby groups may support grandfathering of permits. In this framework, a cost-minimizing industry endowed with few free permits favors an auction because this allocation rule strengthens its political influence and empowers the industry to lobby for a greater share of the emission cap or rather a higher amount of permits and in consequence minimize the permit price.[6]

Within the revision and the preparation for a post-Kyoto period of the EU ETS, one central point is the intensification of auctioning allowances from 2013. The proposal of the EU Commission concerning the revision of the EU ETS considers a replacement of the limited use of auctioning allowances (a 5% cap

[4] For an overview of the concepts of grandfathering and auctioning, we refer the reader to Cramton and Kerr (2002).

[5] In economic literature, this mechanism is called the "double dividend." The double dividend of an emission tax or an emission trading system results on the one hand from reducing emissions (ecological dividend) and on the other hand from increasing welfare by using the revenues from the tax or the auctioning of permits to diminish existing tax distortions (economic dividend). For an overview regarding the double dividend hypothesis, the reader is referred to Goulder (1995).

[6] Lai (2008) shows as well that grandfathered permits will raise the industrial endowment effect and strengthen the environmental group's lobbying power. Hence, in the case that the emission cap is defined in the subsequent stage, environmentalists will support grandfathered permits within this public choice context. The empirical analysis of Svendsen (1999) arrives at the conclusion that environmental lobby groups in the US advocate grandfathering in order to arrange stricter reduction targets.

in the first and a 10% cap in the second trading period) by auctioning of at least 60% of the total number of allowances. This consists of a full auctioning approach within the power sector and a partial auctioning of 20% for energy-intensive industries.[7]

When the initial allocation is complete, trading can start. Companies that have more certificates in their portfolio than they need (net suppliers) can sell these certificates on the market to companies (net purchasers) that have to cover their emissions with additional permits. Thus, the certificate price results from the interaction of the supply of certificates (the emission cap) and the demand behavior of emitting firms (the aggregate marginal abatement costs). In principle, in the presence of perfect information, no transaction costs, a perfectly competitive trading market, and no government intervention, trading will result in an economically efficient outcome independently of the initial distribution of permits (Montgomery 1972), because marginal abatement costs are equated in any equilibrium.[8] Conversely, this independence result does not necessarily hold when there is uncertainty (and firms are risk averse), when there are transaction costs, when some firms have market power in either allowance or product markets, or when firms receive different regulatory treatment. Also, when some market participants are not minimizing costs or when current allocations are tied to production in previous periods, allocations may become important (Hahn and Stavins 2010).

Some recent work has considered the extent to which emission markets operate efficiently. An active market has developed for allowances on the European CO_2 market (Parsons et al. 2009); this liquidity is a necessary condition for market efficiency. One consideration in this context concerns transaction costs. The existence of transaction costs can lead to a wedge between market participants' marginal costs. Thus, allowance prices diverge from the zero transaction cost

[7] We cannot deal with the whole revision process concerning the centralization and harmonization of cap setting and allocation rules, the enlargement of the scope, the competitiveness of covered sectors, and the integration of third countries to increase the effectiveness of the EU ETS in this article. For an overview, we refer the reader to Ellerman and Joskow (2008) and Convery (2009).

[8] By contrast, Chichilnisky and Heal (1994) point out that the presumption that equal marginal abatement costs are the correct condition for efficiency is not strictly correct. The reason for this is that, simply, a dollar to a person in the developing world does not have the same welfare implications as a dollar to a developed world person. What matters are the real opportunity costs. Formally, the authors find that Pareto efficiency requires the marginal cost of abatement in each country to be inversely related to the country's marginal valuation for the private good. This has strong policy implications: if richer countries have a lower marginal valuation of the private good, then at a Pareto-efficient allocation, they should have a larger marginal cost of abatement than the lower-income countries. With diminishing returns to abatement, this implies that they should push abatement further. Summarizing, the allocation of property rights in a tradable permit system is important for efficiency, not merely for distribution, if environmental quality has a direct impact on wellbeing and marginal valuations of private goods differ strongly across countries.

competitive equilibrium.[9] Another question is whether prices are, in fact, unpredictable, as the efficient markets hypothesis suggests. Applying technical analysis and naïve forecasts, Daskalakis and Markellos (2008) show that three of the most important spot and future markets for European CO_2 allowances deviate from the weak form of market efficiency. That is, returns of CO_2 allowances exhibit predictability and simple trading methods can be applied to generate significant risk-adjusted profits. These findings may be traced back to the facts that the EU ETS currently still suffers from immaturity and features constraints regarding short selling and banking.[10] A third consideration is the intertemporal efficiency, that is, the link between spot and futures prices. Accounting for price dynamics of CO_2 future contracts of the EU ETS, Uhrig-Homburg and Wagner (2009) find that spot and futures prices were linked by the cost-and-carry approach between December 2005 and the end of the first trading period.

In the long run, direct and indirect linking of the EU ETS with other regional or national systems will offer an opportunity to increase liquidity of and participation in the market for tradable allowances, thus improving the functioning of the market. By an intensified linking of the EU ETS, any given global reduction target could be implemented at lowest cost (Jaffe and Stavins 2007). Furthermore, the linking of separate tradable permit systems could form an important element of a post-2012 climate policy architecture and endorse negotiations about ecologically more effective reduction targets (Jaffe et al. 2009). In the short term, the EU ETS has focused on (indirect) linkage with emission reduction credit programs like the Clean Development Mechanism of the Kyoto Protocol.

2.2 *Emission tax*

The emission tax is a near relative of emission trading.[11] While emission trading focuses on the amount of emissions that are allowed in general, the emission tax focuses on the price side of this relation. Because different companies may have different abatement costs, they will react in different ways to an emission tax. Some companies will reduce more than others. If the tax is higher than the marginal costs of abating, at least some emissions will be reduced by the company.

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[9] Cason and Gangadharan (2003) use laboratory experiments to show that in a setting with decreasing marginal transaction costs, the prices and traded quantities vary less from the efficient level if the initial distribution of allowances is not accomplished cost effectively. The reason is that a more deficient distribution of allowances is in need of a higher transaction volume to accomplish the cost-effective allocation, which induces lower marginal transaction cost in a framework of decreasing transaction costs. Furthermore, in the case of constant marginal transaction costs, transaction prices and traded quantities are independent of the incipient endowment.

[10] Ellerman and Montero (2002) empirically evaluate the temporal efficiency of the US Acid Rain Program allowing for trading and banking. They find that in contrast to the general perception of excessive banking in this program, banking worked efficiently.

[11] Subsidies essentially work symmetrically, and we do not explicitly discuss them here. Olsson et al. (2006) discuss them in the European context and provide experimental evidence on their competitive impacts.

This will happen as long as the tax rate is as high as the costs of abating the next unit of emissions. If the tax rate is chosen in a way that is as high as the price would be in an emission trading scenario, then there would be no difference between these two ways of climate protection.

Calculating the optimal tax rate (or the optimal level of emissions with a tradable permit program) of course requires substantial knowledge about benefits and costs of mitigating emissions. Applied to the context of climate change, what is the optimal policy? Cline (2004) found a path for optimal carbon tax and optimal percent cutback in emissions with the DICE99CL model. He found that an optimal abatement strategy should be very aggressive with an emission cutback of about 35%–40% in the early stages, increasing to 50% by 2100, and 63% by 2200. Therefore adequate carbon taxes would be necessary, which should be about US $170 per ton around the year 2005, rising up to US $246 by 2025 and US $367 by 2055. It is obvious that these numbers are of a different order of magnitude from what is being discussed right now for possible CO_2 taxes.

2.3 Hybrid systems combining emission trading and emission taxes

The prices seen on the European CO_2 market are of a different order of magnitude from the prices calculated by Cline (2004). In Fig. 1, we present the Intraday Spot Price from the start of emission trading at the European Energy Exchange (EEX) and BlueNext on 9 March 2005 up to the most recently available data.

As one can see from the data presented in Fig. 1, during the year 2006 the emission permit price varied between €10 and €30, which is far from the emission prices that have been calculated by Cline (2004). Even in that time period, we

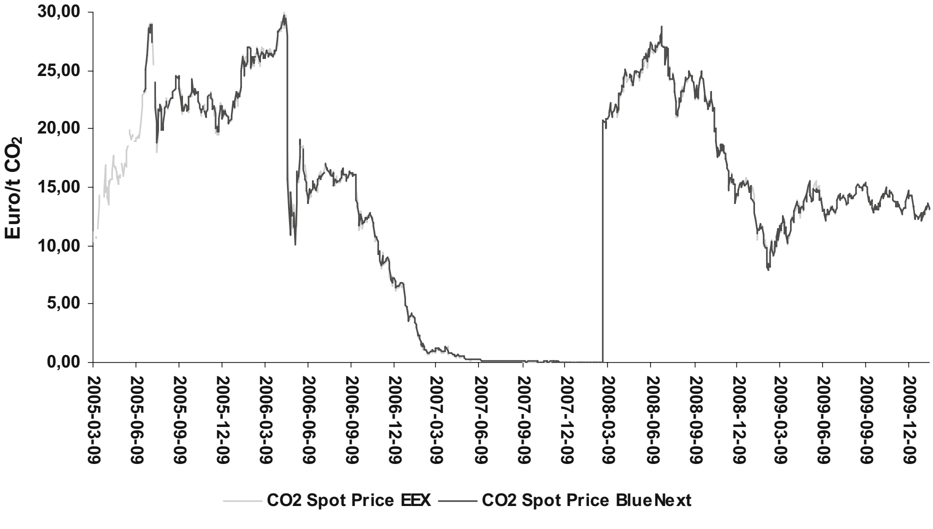

Fig. 1. Spot price of a ton of CO_2 permits on the European market. On 21 January 2010, the exchange rate was €1 ≈ US $1.41. Source: BlueNext, European Energy Exchange

can thus conclude that the EU ETS does not achieve social (or allocative) efficiency. The cost effectiveness of the reduction may also have been constrained simply because little reduction of emissions was required. Trading did take place (in fact, trading volume in the ETS rose more quickly than it did at the start of the SO_2-permit trading program under the Clean Air Act amendments of 1990), but in the absence of a baseline of how much trading should have occurred, it is hard to evaluate the outcome.

The price path of CO_2 permits in the EU is not only noteworthy for its level but also for its highly volatile behavior. Despite the fairly low expectations of maximum price caps of about €15, the permit price climbed up to €30 until spring 2006. A few days later, the information that the market as a whole was "long permits" began to circulate, meaning that too many permits were allocated. This emerging of an overallocation in the trading sector of the EU ETS resulted in a price collapse unusual for commodity markets. This episode illustrates that there is significant uncertainty in the market. Part of it probably has to do with the fact that emission trading is a new policy for Europe, but part is inherent in the way the market is set up. Because of banning the possibility of transferring permits from one trading period to another by most member states and the resulting lost in value of the CO_2 permits with the new trading period in 2008, the price effects following from overallocation were intensified.[12] Parsons et al. (2009) provides a discussion of this problematic design feature. Nonetheless, even without these institutional features there is significant uncertainty. The spot price ranging initially between €22 and €27 illustrates the increased value of CO_2 permits generated by stricter allocation caps for the second trading phase.

The key assumption that drives the equivalence between emission permits and emission taxes in the previous two sections is the absence of uncertainty. In particular, the regulator was assumed to know exactly what upper bound to set on emissions or what tax rate to set in order to achieve the social optimum. The price is defined by the tax in that the optimal level of abatement is generated while the quantity-based approach can be used to fix the optimal quantity to generate the market price. In practice, however, uncertainty is rampant. Indeed, both the (marginal) costs of abatement of greenhouse gas emissions and the (marginal) benefits of avoiding climate change are highly uncertain. For example, Pizer (2002) calculates that the marginal cost of achieving the 1990 emissions level in 2010 would involve a marginal cost between US $0 and US $180 per ton carbon[13] (for a 95% confidence interval). The marginal benefits are approximately constant independent of the reduction of emissions, and are between US $0 and US $24 per ton carbon.

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[12] The so-called banking of emission allowances shifts permit trading into future trading periods and consequently represents an instrument of risk management with respect to drastic price changes and allowance shortages (Maeda 2004). For an analysis of the reduction of abatement costs via banking of permits in the Kyoto framework, see van Steenberghe (2005).

[13] One ton of carbon corresponds to 3.67 tons CO_2.

As Weitzman (1974) shows in his seminal paper, price instruments (like taxes) and quantity instruments (like emission permits) behave asymmetrically in the presence of benefit and/or cost uncertainty.[14] In this setting, an environmental agency has to choose the instrument of pollution control ex ante with regard to the expected degree of welfare being generated ex-post. Weitzman's main result is that taxes minimize the deadweight loss from choosing the wrong policy if the marginal costs of abatement are steeper than the marginal benefits, while emission permits are preferred otherwise.[15] Because of the features of cost and benefit functions in the context of climate change, some researchers therefore argue for the superiority of taxes as a policy instrument for climate change. Intuitively, because marginal costs are assumed to be steeper than marginal benefits, taxes are preferable because they put a fixed upper bound on the costs firms will have to bear. By contrast, emission permits may produce, in equilibrium, an extremely high price that may create substantial overall efficiency losses.[16]

In a dynamic setting, Biglaiser et al. (1996) show that under the assumption of complete information, a quantity-based approach may not induce the social optimum even if the market is perfectly competitive because an optimal system of tradable permits exhibits time inconsistency. By contrast, tax approaches to regulate pollution may be able to achieve the social optimum and feature time consistency. Montero (2002) shows that with incomplete enforcement and cost and benefit uncertainty, a quantity instrument performs relatively better than a price instrument; when marginal benefit and cost curves have the same slope, the quantity instrument should be preferred. The reason for this preference is that incomplete enforcement is endogenous to the actual cost of control. Under incomplete enforcement, unexpectedly high costs cause noncompliance of some firms, and thus the advantage of prices over quantities is mitigated. On the other hand, Newell and Pizer (2003) find that in a setting of stock pollution with rising optimal stock levels, more efficient control is often provided by a price-based approach. Overall, there is no definitive advantage of either prices or quantities; the relative dominance depends on the circumstances.

Economists have long considered ways of combining the advantages of emission trading with the advantages of emission taxes (Roberts and Spence 1976).[17] One such hybrid instrument uses certificates as the main instrument, but there is

[14] We comment on other differences below.
[15] The analysis of Adar and Griffin (1976) using quadratic cost and benefit functions provides the same results while Weitzman's findings are based on approximately quadratic cost and benefit functions.
[16] Newell and Pizer (2003), for example, find that taxes generate up to nearly five times the expected welfare gains of tradable permits in a 40-year horizon.
[17] We do not deal with a combination of marked-based instruments with environmental standards for certain regions here. The aspect of a combination of permit trading and ambient concentration limits is considered by Krupnick et al. (1983) and McGartland and Oates (1985). The SO_2 permit trading program under the Clean Air Act amendments of 1990 and the usage of a tradable permit system for NO_x and SO_2 under the Regional Clean Air Markets (RECLAIM) in Los Angeles can be cited as real implementation of a combination between a tradable permit approach and environmental standards (Bennear and Stavins 2007).

a backup system that should protect the participating companies from an extreme increase in prices for the permits. This backup system works with a so-called safety valve that gives companies the possibility to buy permits from the national authority at a fixed price that is usually higher than the expected market price. For the case that the market price does not develop as expected, companies have an option to buy certificates at a fixed price. This makes it easier for companies to undertake the necessary calculations because they have an overview of the maximum costs they may be faced with. Companies can choose whether to buy permits in the market or to buy them from the national authority, but their choice will depend on the market price. However, if the market price is higher than the trigger price, companies will pay the trigger price to the national authority, which can be seen as a tax per unit of emission. As long as the price of the permits is below the trigger price the system will work like a trading scheme providing cost efficiency with uncertain costs and a fixed amount of emissions. If the trigger price is reached because of abatement costs higher than anticipated, a so-called safety valve is provided and the system changes to a tax scheme with fixed costs but uncertainty over the level of emissions. Roberts and Spence (1976) show that the simultaneous implementation of price and quantity approaches minimizes expected total costs in contrast to the isolated usage of a price-based or quantity-based instrument. The application of this hybrid system can be interpreted as protection of each instrument against the malfunction of the other.[18]

Figure 2 shows how the hybrid system works (cf. Jacoby and Ellerman 2004). The national authority allocates permits in the amount of Q_1. Marginal social

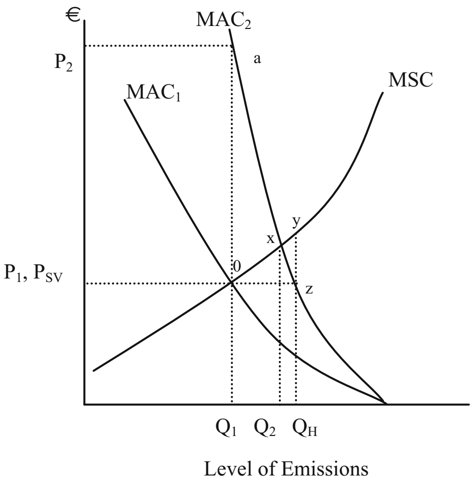

Fig. 2. A hybrid system

[18] Baumol and Oates (1988) study a hybrid system that allows the firms to sell their permit to the government if the price falls below a certain "price floor," which can back up dynamic inefficiencies.

costs of emissions are described by MSC. If the marginal abatement costs are low, as is shown by the marginal abatement cost curve 1 (MAC_1), the market price for certificates will be P_1. But if marginal abatement costs turn out to be high as is shown by the marginal abatement cost curve 2 (MAC_2), the resulting market price would be P_2. This is much higher than expected, leading to an efficiency loss, because the quantity of permits should have been higher. This is where the hybrid policy comes in. In this policy, companies can buy additional permits from the national authority without limit at a safety valve price P_{SV}, and overall costs will be much lower as in an emission trading system. Due to the higher level of abatement costs, emissions are abated to level Q_H and permits in the amount of $Q_H - Q_1$ are bought.

Finally, the level of emission under the hybrid system Q_H will be slightly higher compared than the optimal level of emission Q_2, which leads to lower total costs under the MAC_1 and higher social cost of the emission level within the range between Q_H and Q_2. The welfare efficiency loss of the hybrid system (the area $x - y - z$) is less than that for the situation without the safety valve (the area in the triangle $0 - x - a$). Therefore, the hybrid system gives companies more security concerning the financial side of the system, because they know the maximum amount of costs that will arise if the trigger price comes into play.

In the economic literature, the implementation of a hybrid system has been seen recently as an important approach in fighting global climate change (Jacoby and Ellerman 2004; McKibbin and Wilcoxen 2002; Pizer 2002). The efficiency gains from the hybrid policy for climate change have been estimated to be substantial. Pizer (2002) uses a modified version of the Nordhaus (1994) DICE model. It is true that the hybrid policy only slightly improves on the pure tax system; the expected social benefits of a global policy to combat climate change are about US $300 billion in both cases. However, both the tax and the hybrid system are dramatically superior to the optimal tradable permit solution, by a factor of five or more. Thus, given that the hybrid system has a significant appeal vis-à-vis the tax system (i.e., the ability to flexibly distribute the rents associated with emission rights), it appears as a very attractive option.[19] To our knowledge, there is no analysis of the relative gains of this instrument specifically for Europe.

How high the trigger price should be is a matter of ongoing discussion. Some argue that the trigger price should be high so that it is used only in unexpected situations when the demand for emission rights increases as a result of unexpected actions. However, if the trigger price is set too high, the basic problem of a deadweight loss in the case of unexpectedly high marginal abatement costs arises. On the other hand, if the trigger price is set too low, not all marginal benefits of reducing emissions are internalized. Numerical results confirm this intu-

[19] A drawback of this prototypical hybrid system is that it necessitates monetary exchanges between the private sector and the government in case the trigger price is reached (which may be seen categorically as a bad idea). Newell et al. (2003) consider policies that replicate the behavior of the policy without monetary exchanges.

ition. For example, Pizer (2002) calculates that the optimal trigger price is very similar to the optimal tax level. If, in 2010, the same world emissions as in 1990 should be obtained, he calculates that the optimal trigger price is around US $20 per ton carbon.[20]

2.4 The innovation and cooperation strategy

We now turn to what at first appears like a completely different way of possible climate change policies, but what, in the end, turns out not to be a separate instrument on its own. The idea behind this strategy has entered public discussion with the consultation of the Asian-Pacific Partnership on Clean Development and Climate (APP). This agreement between Australia, Canada, China, India, Japan, South Korea, and the USA is focusing on a new way to achieve climate protection hand in hand with economic performance. The partners of this agreement want to focus on the development of new technologies and an increased cooperation in developing and distributing these technologies. The idea the governments involved in this partnership had when they founded this partnership was that innovation of new technologies reduces greenhouse gas emissions, which helps them to fulfil their climate protection targets and provide a higher level of energy security. As a side effect of these technology advances, indeed, economic theory suggests that only technological progress can boost economic growth in the long run.[21]

Since July 2008, 123 projects have been registered in which government agencies and companies from the sectors of aluminum, buildings and appliances, cement, cleaner fossil energy, coal mining, power generation and transmission, renewable energy and distributed generation, and steel are involved. Some illustrative examples of the APP's project activities include the management of bauxite residue in aluminum production, the promotion of a standardized energy-efficient lighting, the transformation of waste to fuel in cement kilns, and the improvement of carbon-capture technology for coal-fired power plants. Furthermore, it covers the development of strategies to guarantee health and safety in coal mining, the implementation of a shared best practice approach in the power generation sector, and the intensification of the usage of solar power and cleaner steel technologies.[22]

[20] Recall that these estimates are based on what is seen by many as an inefficient goal of emissions reductions themselves. The estimates of Cline (2004) optimize both the quantity and the price.

[21] This was recognized already in Solow (1956). Only more recently did economists think about how technological progress develops endogenously. The seminal contribution is Romer (1990), but a huge literature, which we cannot review here, has since followed. We refer the reader to Barro and Sala-i-Martin (2003) for a comprehensive overview.

[22] Detailed information of the different sectoral projects and outcomes of the Eighth Policy and Implementation Committee Meeting in October 2009 can be found under http://asiapacificpartnership.org/default.aspx.

The basic question, though, is: what are the incentives for technological progress? Like for any other economic activity, people may have intrinsic incentives, but for most entrepreneurs engaging in the business of technological innovation, there is also an extrinsic part. A useful framework for thinking about technological progress has been provided by Schumpeter who separated technological progress into three different phases. The first one is called invention and is defined as the phase in which new ideas are created. In the second phase, these ideas have to be developed into commercially useable products. This phase is called innovation. All these innovations can only push an economy forward if they are widely used. This happens in the third phase of the cycle of technological change named diffusion. The critical point is that each of these phases is guided and regulated by incentives. Incentives come from outside effects like (relative) prices or official regulation.

One way to interpret the APP is that it wants to give the same relative incentives as other existing policies in Europe and elsewhere, but with a different method. In particular, one interpretation is that it favors rewarding environment-friendly technologies rather than punishing environment-hostile technologies. Economically, the effect is the same and the two approaches are isomorphic, but politically they may be worlds apart. Where the first three approaches discussed in this article use taxes and quantity restrictions, it is likely that the Asia-Pacific Partnership would favor research subsidies. They might also consider a policy innovation such as "minimum number of inventions bonds" (the rough equivalent of a quantity instrument).[23] These instruments would be set with very similar goals in mind as discussed before: social efficiency and cost effectiveness.

Of course, participating countries tend to have different interests concerning environmental protection and economic development. Therefore, because a common environmental target is missing in contrast to the Kyoto targets, each country will try to maximize its utility, which may inhibit the effectiveness of the Asia-Pacific Partnership being based so much on cooperation. Moreover, one problem with subsidies is that they can be misappropriated fairly easily. La Porta et al. (1999) indeed show a positive correlation between government transfers and subsidies and corruption, although the overall evidence and interpretation of this correlation is less clear. Buscaglia and van Dijk (2003) found that "high levels of corruption are associated with high distortions and abuse of discretion in the granting of state subsidies to the private sector." Olsson et al. (2006) discuss further implementation issues if subsidies were to be used in Europe. One aspect that we cannot deal within this article is how the international diffusion of technological progress is governed. Difficult issues in industrial organization,

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[23] Recall that an emission permit allows a company to emit a ton of a particular pollution, thus causing social damages. Similarly, with an "invention bond" a company would be allowed to receive the right to use a new technology. Companies that are not innovative enough to invent themselves are better off buying these bonds, leading to a more efficient social allocation. Clearly, this is rather utopian, but the basic principle should apply here.

international intellectual property law, and other areas are relevant here, and they have to be analyzed separately.[24]

In short, we challenge the view that this is a separately viable economic instrument to combat climate change. Not only is it relatively obscure how precisely this approach would be put into operation, but it is also clear that it is practically meaningless without a price system that is supported by one of the three core approaches discussed earlier.

3 Additional criteria for choosing between instruments

So far, we have discussed the four instruments mainly in terms of efficiency and cost effectiveness. All market-based instruments are likely to yield cost-effective solutions, and their efficiency always depends on the degree of information the policymaker can secure regarding optimal pollution levels. In this section, we consider additional criteria for choosing among instruments, in particular, ecological effectiveness, political feasibility, financial impacts, and dynamic incentives. It is important to evaluate these criteria for all instruments at the same time. In evaluating the instruments, we also draw on existing experiences especially in Europe. As discussed earlier, uncertainty is perhaps the dominating aspect of climate change policy and therefore is an extremely important criterion for evaluating policy choices. It permeates all the issues discussed in this section. We have studied one important aspect (the question of deadweight losses) above, and we will return to the issue of uncertainty again in Sect. 4, where we ask how we can approach it using a market-based instrument.

3.1 Ecological effectiveness

Ecological effectiveness describes how well an instrument works to reach the environmental goal the policy focuses on. Emission permits and emission taxes, which are near relatives to each other, have one of their biggest differences in this point. Emission trading sets an overall cap of emission allowances that are supplied to the companies that take part in the system. This cap is limiting overall emissions from the emission trading sector. Ecological effectiveness therefore is, at least in theory, 100% because no more emissions than allowed should be

[24] Recent work has revealed that a technology transfer from a developed country (north) to a developing country (south) in a situation with no trade, the north country will, in equilibrium, and even if the technology is transferred free of costs, always like to transfer the technology to the south. The south will always be better off if it accepts the technology. In this case, the global pollution level will always stay within the initial levels. In a second step, trade was introduced between north and south and different outcomes were found. In this two-commodity model, the north is specialized in the production of the nonpolluting commodity and south is specialized in the production of the polluting commodity. The north could be better off if it transferred technology, but once it decides to transfer then it would be done completely. The technology transfer cannot guarantee a stable global emission level under a trading scenario (Mukherjee and Rübbelke 2006).

emitted.[25] Because emission trading is a new instrument in European environmental policy, not much experience has been gained as yet. Experience in the United States with an SO_2 trading system that started in 1995 has shown that the allowance trading program had positive welfare effects, taking into account both ecological and economic aspects, with benefits six times greater than costs (Stavins 2003). As mentioned earlier, while the quantity is fixed (at least to the extent that emissions can be properly measured), the price of emissions and abatement is uncertain.

In contrast to an emission trading system, an emission tax system cannot guarantee an exact amount of emissions as the outcome. The reason is that with a fixed price of emitting that is set by the tax and unknown marginal abatement costs, the reduction of emissions is uncertain. The reduction can be higher than in a trading system if the tax is higher than the market price, but the reduction can be lower if the tax is below the market price. Ecological effectiveness of a tax system depends on the tax rate, which should be set ideally with the knowledge of the marginal abatement costs. Usually, these costs are only available to each individual company but not to the authority and therefore the tax has to be set without this information. Thus, meeting an environmental target with a tax is difficult and the tax has to be adapted until the initial target is reached. This trial and error process needs time and is difficult in a political context if the system of emission taxes is not commonly agreed upon by all political parties. In other words, the standard, static uncertainty analysis by Weitzman (1974) and others that is already discussed above has to be extended by including dynamic aspects. If the deadweight losses in one period of time turn out, ex post, to have been too high, then in the next time period the instrument may be adjusted. However, even if adjusting the tax rate were to be socially optimal, such an adjustment would not necessarily be politically possible. In other words, political inertia can be an additional cost of choosing the wrong tax rate in the first place.

Experience with taxes in Europe has shown different results. In Norway, for example, high carbon taxes have led to low effects on emissions. This may be because the tax does not work for the sources in which it was levied and was not used for other sources where it would have worked (Bruvoll and Larsen 2004). Simulation of the effects of ecological tax reform in Germany has shown that a reduction of CO_2 emissions can be achieved without jeopardizing employment. In the model, CO_2 emissions are reduced step by step until they are 3% lower than in the business-as-usual scenario without ecological tax reform in 2010, whereas GDP increases by up to 0.5% and employment increases by around 0.75% when compared with the business-as-usual scenario (Kohlhaas 2005).

The hybrid system combines the trade and tax systems not only in institutional settings but also in the issue of ecological effectiveness. Thus, the ecological target is reached as long as the hybrid system is moving in the trade area of the system. If the trigger price is reached and additional certificates can be bought from the

[25] This does not mean that the correct target is met, but that the society can meet the target with certainty.

national authority, the certificate cap increases and the ecological target becomes diluted and the outcome is unclear. One can see that the ecological effectiveness of the hybrid system depends on the setting of the trigger price. If the trigger price is set near the market price for emission allowances, then a small increase in demand can increase the price for the allowances over the trigger price. In this case, allowances can be bought from the national authority and the ecological target is missed. Therefore, the policy should be designed with a trigger price high enough so that it is only reached in unpredictable situations to keep the focus on the environmental effect of the system.[26]

Ecological effectiveness is a problematic point in the innovation strategy. The output of research and development, one of the most important points in a good working innovation strategy, cannot be easily predicted. The potential that new inventions have to protect the climate are hard to foresee in advance. It is impossible to say that new inventions in the next 10 years will reduce emissions by 50% because nobody knows exactly what environmental protecting potential new inventions will have. Because there are no binding goals in this strategy, the whole ecological effect will depend on the progress of technology, on the intensity of international cooperation, and on the exchange of technologies between countries or even companies. All these aspects are hard to predict. We return to this issue, and especially the possibility to forecast future technologies using market-based tools, in Sect. 4.

3.2 Political feasibility

Political feasibility implies the level of acceptance that a policy has in the public eye. If more (and more powerful) people are in favor of a certain policy, it is easier for the political authority to implement this policy without compromising their chances for reelection. This is a major incentive for governments in their choice of policy instruments.

One relevant factor influencing the feasibility of a policy is the number of people that are affected by the policy. For example, in the case of a tax, this factor is defined by the amount of money that the tax costs each individual. In the case of emissions this article is focusing on, that means how the broad public or the majority of voters are affected by emission trading, taxes, or other policies. However, with interest groups playing an important role in political decision making, small lobbies may be powerful when it comes to negotiations about new political activity. Representatives of the industry sector, which is made up of few people in comparison with, for example, the large number of workers that are represented by the unions, may have a lot of political power because of the capital they represent.

[26] Murray et al. (2009) pick up the potentially insufficient ecological effectiveness of a cap-and-trade system with a safety valve and suggest an allowance reserve approach. This system provides a fixed price ceiling and a maximum number of permits to be issued, which means that the ecological target is supported by ensuring a quantitative limit of permits.

In the case of emission trading as it is used today, most people are not directly affected. In Europe only large companies in electricity generation and industry have to take part in the emission trading system while small businesses and households are excluded. From this point of view, emission trading has a good political enforceability. Voters are indirectly affected, however, through increasing prices that are the results of the higher costs companies are faced with. However, as it is difficult for consumers to have an exact view of the reasons for increasing prices in detail, emission trading can be seen as an instrument relatively easily implemented. Stavins (2007) argues that environmental advocacy groups (generally supporting command-and-control instruments) strongly prefer tradable permits vis-à-vis a tax approach because the price-based policy generates a highly visible cost of environmental protection. Regarding permit allocation, an allocation without charge may be easier to implement than taxes or auctioned permits, because the industry's mitigation cost are less visible and less burdensome. Furthermore, free allocated permits alleviate forming majority coalitions by providing more control to regulate the distributional effects.[27]

It may, however, also be the case that people do not like the uncertainty that goes with new policies. In this case, they will be more opposed than they should be. Of course, that argument may be moderated once one considers the active and powerful role of lobbies, sometimes of small but important constituencies, play in shaping the policy process and its outcomes.

Taxes are frequently viewed with skepticism. Thus, introducing an emission tax has to be done carefully if a government does not want to lose its mandate at the next election. As is the case in a trading system, the number of people who are directly affected by the tax will affect the acceptance or otherwise of the tax and the chances for reelection of the government. Because additional taxes on emissions will increase the prices of different goods, amongst others electricity, nearly all people are affected at least indirectly by such a policy.[28]

A hybrid policy is, as the trading policy, a strategy that is not well known among the broad population. At least in terms of its principles, it can be "sold" as something other than a tax, giving it a natural advantage. The empirical analysis by Pizer (2002) shows that a hybrid system is only slightly more efficient than a pure tax approach. But with regard to political feasibility, the hybrid policy may be favorable to a pure price-based approach because on the one hand it provides

[27] With regard to the political economy of market-based environmental policy, we refer the reader to Joskow and Schmalensee (1998) who examine the political process of permit allocation within the US Acid Rain Program.

[28] There is little systematic evidence on how people feel about environmental taxes. Halla et al. (2008) analyze how satisfaction with democracy in European countries varies with environmental quality and policy. They find that citizens in countries in time periods with higher environmental or energy taxes tend to be less satisfied with the way democracy works in their country, but citizens are more satisfied if more environmental policies are enacted. They explain this result with the fact that a measure of the quality of democracy is how well it resolves collective action problems, but that by and large individuals prefer not to pay for environmental quality.

(in the case of gratis allocation) acceptance within the industry sector and on the other hand allows distribution of the rents generated from the additionally sold emission allowances (Bennear and Stavins 2007). Thus, the task of implementing the policy should incur less resistance from the majority of the population.

The political enforceability of different systems can be very different from country to country. On a general level, Europeans are more used to taxes as a regulating instrument, so it is easier to implement such a hybrid instrument than in the United States where taxes are seen as an evil from the very first idea and a lot of work has to be done to convince people of the benefits of such a system. From this perspective, it is quite puzzling that Europe adopted an emission trading program for CO_2 in the first place.

The extent to which the public is concerned by a hybrid system depends on its design. The number of companies or individuals that are affected depends on the approach used. If an upstream approach is used, far fewer companies are affected because the system starts working at the top of the carbon chain, namely importers and producers of fossil fuels, while a downstream approach affects many companies and individuals as the duty of providing certificates is shifted into the direction of the end users (Boemare and Quirion 2002). Furthermore, the choice of sectors that are regulated by a trading system affects the public. It makes a difference if only the energy sector is captured by an emission trading system or if public and especially private transport are included.

From the political side, the innovation strategy seems to be the easiest one to implement. Companies are not faced with any binding reduction targets or taxes and therefore prices for energy and products that require fossil resources do not increase as a result of the policy. Because technological progress and innovation are positive signs for an economy, political authorities will find it easy to support research and development without compromising their chances in the next election. However, once one thinks about the second part of the innovation strategy, namely, the coordination of technology transfer, one becomes more doubtful about the ease of implementation. Loosely speaking, every country has an incentive to free ride. Worse still, that incentive is not only present in the technology-sharing phase, but already in the innovation phase. In the worst case, all incentives for technological progress might evaporate.

3.3 Financial impacts

Financial impact in this context implies how consumers in a country with a regulation policy are affected in monetary terms. Because all policies increase costs of companies more or less, the question is how companies will pass on these costs to consumers.

Practical experience with emission trading in the European Union has shown that although emission certificates were allocated for free, companies have integrated the costs for certificates as real costs into their calculation and prices have increased (Woerdman 2001). This has been apparent since the start of the European emission trading scheme, especially in the electricity sector. Sijm et al.

(2006) show by empirical estimates that the pass-through rates of costs of CO_2 allowances for the power sectors in Germany and the Netherlands vary between 60% and 100% depending on the carbon intensity of the marginal production unit and various other market-specific or technology-specific factors. *Verband der Industriellen Energie- und Kraftwirtschaft* reported in May 2006 that the German energy sector makes an annual surplus of €5 billion by including the price of certificates into their electricity price calculation (Verband der industriellen Energie-u. Kraftwirtschaft 2006). For the UK, calculations show an increase of wholesale power prices of £3.50 to £10.50 per MWh over the forecast period to 2020 as a result of these windfall profits.[29] This should increase the profit of the UK power generation sector by £800 million per year (IPA Energy Consulting 2005). In theory, the ecological effects of regulation and the financial impacts should be the same as with a tax policy and who has to bear the additional costs should depend on the slope of the respective supply and demand curve.

In the hybrid system, the same logic applies. Companies are faced with higher costs as a result of the policy, and they may be able to pass on the costs. Whether companies or consumers pay the larger part again depends on the slope of the demand and supply curves.

For research and development policy, it is difficult to predict the financial impacts. First they depend on who is financing research and development: government or companies. If we talk about publicly financed research and development, it is clear that it has to be financed through taxes. Thus, taxes have to be either increased (which is frequently distortionary and thus creates social costs) or public spending has to be cut in other areas to leave taxes unchanged. Firms can engage in research and development on their own to realize comparative advantages. The government may also decide to motivate companies, if firms do not engage in a socially efficient level of research and development on their own. As discussed in more detail in the next section, incentives for companies to start research and development activities can come from an emission trading program or from taxes, both of which increase the price of emitting CO_2 and force companies to find measures not to pay these additional costs.

In terms of political feasibility, promotion of research and development through lower taxes or tax deductions has the advantage of neutrality concerning decisions about the topic and the character of research projects on the companies' part. Taxation benefits present only a small barrier for companies to obtain financial support, which is especially important for small and middle-sized companies. The conditions to receive a benefit are transparent compared with other methods of public support, and for companies it is easy to plan because the rules of receiving a tax reduction are known in advance (Hutschenreiter and Aiginger 2001). However, in contrast to an innovation program where a fund is fixed for each period, a tax incentive amounts to losses in tax revenue, which leads to higher or new taxes to compensate for this loss.

[29] On 21 January 2010, the exchange rate was £1 ≈ US $1.62.

3.4 Dynamic incentives

Besides analyzing the static cost efficiency of environmental instruments, the generation of dynamic incentives for technological change and innovation play an important role, whereas the innovation and cooperation strategy is not the only policy that requires the consideration of dynamic aspects. Other policies should also be designed to encourage companies to continuously improve their emission reduction techniques. Market-based policies such as tradable permits and taxes not only have the static advantage of cost effectiveness, but also dynamic incentive advantages.[30] Snyder et al. (2003) show empirically that change of relative prices induced exogenously or by the implementation of a certain policy may provoke technological change, and, thus, the achievements of different policy instruments can vary. In general, it is important to assess the effects of a preexisting framework of regulation while evaluating the effects of alternative instruments on technology innovation and diffusion.

An emission tax provides a continuous incentive for reducing emissions, because every unit of emission that is not emitted saves money for the company. As long as reduction measures are cheaper than paying the tax, companies will engage in research to reduce emissions or adopt existing emission-reducing technologies. An emission trading systems provides, in principle, the same dynamic incentive as a tax system. Every unit of emission a company does not emit provides an additional certificate saleable on the market. Thus, companies are interested in reducing emissions because it also reduces their costs.

Within the analysis of an emission trading system with respect to the dynamic incentives, a distinction regarding the possible allocation metrics has to be made. Under the assumption that the diffusion of new technologies reduces the demand for permits relative to the supply and therefore reduces the permit price, grandfathering diminishes the incentive of emitters covered by the system to evolve environmental innovations. The higher the diffusion of new technologies, the higher the value of the permit and the benefits from selling surplus permits is reduced so that a free allocation constrains the dynamic incentives. By contrast, the auctioning of permits generates the incentive to use new technology because in the long run costs from purchasing permits can be reduced (Milliman and Prince 1989).

Because a hybrid system combines tax and trade systems it also has the dynamic incentive of continually increasing reduction efforts. As in the two former cases the dynamic as a whole depends on the price. The higher the price or the tax, the longer a dynamic incentive to reduce emissions is given.

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[30] Other policies should also be designed to lead companies to improve their emission reduction techniques continuously. Recall that in the case of an emission standard companies do not have any incentive to improve their technology once the level set by the authority is reached. This policy, which is not part of this paper, has no dynamic incentive at all. For an empirical analysis concerning the dynamic incentives of environmental regulation by taxes, technology adoption subsidies and technology standards we refer the reader to Jaffe and Stavins (1995).

The dynamic incentives of the innovation strategy depend on the design of the research and development policy. If research and development is supported by national authorities, the direction of research and development activities can be guided as well as the range of the different sectors that should be covered by the activities. The dynamic incentive or the incentive to permanently increase the level of technology depends in some way on the will of the authority and the financial support it is providing to research and development. If a national authority is interested in a permanent technological improvement, the financial, organizational, and political background must be provided. If these preconditions are set, the chances for permanent progress in environmental technology are given.

4 Dealing with uncertainty

As discussed earlier, both emission permits and taxes are cost-effective instruments, which means they allow society to achieve a specified quantity or price goal at minimum cost. We discussed earlier how the economic efficiency of emission permits and taxes depends on the quality of information the regulator has about benefits and costs, and how hybrid instruments have been proposed to combine the best of both. For the innovation and cooperation strategy, it is much more difficult to predict even theoretically what will happen, simply because innovations are, by nature, hard to predict. There is a very strongly market-based tool that allows feasible policy decisions in such a context, which is called a "prediction market."

It has long been known that speculative markets do a great job of aggregating relevant information. In fact, they often perform better than forecasting institutions and Roll (1984) has pointed out that orange juice futures improve on weather forecasts. Horse race markets beat horse race experts (Figlewski 1979). The Economic Derivatives market run by Goldman Sachs and Deutsche Bank outperforms economists in predicting economic outcomes (Gürkayanak and Wolfers 2005). Oscar markets (e.g., the Hollywood Stock Exchange) make more accurate predictions than columnists (Pennock et al. 2001). Both real and play-money markets have generated more accurate forecasts of the likely winners of NFL football games than all but a handful of 2000 self-professed experts (Servan-Schreiber et al. 2004). Election markets beat national opinion polls (Berg et al. 2001), and corporate sales markets beat corporate sales forecasts (Chen and Plott 1988). Prediction markets have also been applied to forecast influenza outbreaks (Nelson et al. 2006). In all of these cases, we are in a similar position as when trying to predict which technology will next be invented and adopted in the case of technology that allows us to diminish greenhouse gases.

Wolfers and Zitzewitz (2008) provide a survey of recent research on prediction markets. Scholars have considered how to translate market prices into probabilities (Wolfers and Zitzewitz 2005). Intuitively, if more people expect that a (well-specified) event will happen, more people will buy an asset that pays off 100 monetary units if that event occurs. For example, suppose we construct a market where an asset is traded that pays off 100 monetary units if the average CO_2

emissions of cars falls below 50 g/km. It is unknown if and when such a technology will become available. However, the market price of such an asset is likely to give policymakers and other firms a good indication of how likely it is. Obviously, there are many implementation issues to be dealt with in this context. For example, what is the exact sample of cars that is considered? Is it just prototypes (in the spirit of Schumpeter's innovation stage) or is it only mass-produced cars? Hanson (2003) shows that even though there may be many thousands or millions of combinations of events that a market might trade, it is still feasible to construct a liquid and informative market. Finally, issues of moral hazard (while having played a role in the closing of the Policy Analysis Market in the USA in July 2003; Hanson 2006) are generally not seen as insurmountable obstacles.

Another issue may also be of concern to policymakers. In some sense, prediction markets establish a derivative market in that the price of the entity being traded depends on the probability that the "underlying," namely, the technology comes into existence. There is a long, but inconclusive discussion in finance and economics whether the introduction of derivatives, such as futures, leads to increased volatility of the underlying. Some have found such an effect; others the opposite; yet others have found no effect.[31] Consider the introduction of a prediction market in a market where firms are already subject to a tradable permit system, such as in Europe. Conceptually, what might happen is that the technology prediction market leads to more volatile views on abatement technologies, thus leading to more volatile emission permit prices. There is, to our knowledge, no study that specifically addresses this concern in the context of prediction markets. An overall assessment of this consequence would also have to determine the economic cost arising from more volatile emission permit market prices and how they compare with the benefits obtained from the prediction market. In particular, firms may suffer from more volatile spot prices. However, volatilities can be hedged with appropriate instruments, and the cost to firms would therefore consist primarily in the costs of the hedge. For example, Chesney and Taschini (2008) provide an approach for CO_2 option pricing. As the market for options on emission permits grows more liquid, this cost decreases, but it will still remain an important factor. Understanding the overall welfare effects of prediction markets in this specific context thus remains an important area for research.

In short, prediction markets in principle appear as an extremely important complement to other market-based policies for combating environmental problems that are surrounded by a great deal of uncertainty. The one potential drawback seems to be an increased volatility of emission permit prices, although

[31] Seminal contributions showing an increase in spot price volatility due to derivatives trading include Figlewski (1981), Stein (1987), Harris (1989), and Lee and Ohk (1992). By contrast, Bessembinder and Seguin (1992) and Brown-Hruska and Kurserk (1995) provide evidence suggesting that active futures markets are associated with decreased stock market volatility. Finally, Santoni (1987) and Edwards (1988a,b) find that daily and weekly volatilities of the S&P 500 are not different after the introduction of futures. Darrat and Rahman (1995) and Darrat et al. (2002) also found no correlation of S&P 500 and DJIA jump volatility with derivatives trading.

existing research indicates that it is far from certain that derivatives are responsible for increased spot market volatility. More detailed analysis of this possibility must be left for future research, but it seems clear that especially the innovation-based strategy would benefit tremendously if accompanied by a market-based forecast of technological innovation and diffusion.

5 Conclusions

All three basic strategies that are presented in this article show potential for addressing climate change. Emission trading has a clear goal concerning the reduction of emissions because the overall cap of allowed emissions is set at the beginning. Environmentalists may favor emission trading from a purely ecological viewpoint, because with the help of the cap it is possible to control the total amount of emissions. Controlling the amount of emissions is more difficult using an emission tax. In this case, the regulator has to have information about marginal abatement costs of the individual companies and the whole economy. This information is not well known, and the optimal tax rate to achieve a certain target has to be set in a trial and error process, which is hard to implement from a political point of view. Because there is much evidence that the marginal cost curve is steeper than the marginal benefit curve in the context of climate change, efficiency considerations at first favor taxes. However, a hybrid system that uses a permit system with a safety valve may also do very well. We have discussed how the different instruments can be evaluated with respect to various criteria. Importantly, they are all cost effective, but they vary with respect to ecological effectiveness, financial impact, dynamic aspects, and political feasibility. The substantial advantages of the hybrid approach, on theoretical, practical, and politico-economic levels lead us to regard this instrument as very promising for the post-2012 period in Europe.

On the international level, climate change is combated by the Kyoto Protocol, an international agreement linked to the United Nations Framework on Climate Change between industrialized, emerging, and developing nations. The protocol's major feature is the provision of binding targets for industrialized countries for reducing GHG emissions to an amount of an average of 5% against 1990 levels over the 5-year period 2008–2012. However, implementation of the Kyoto Protocol has been criticized by economists with respect to the nonparticipation of key countries of the global GHG emission, the short time path of action, and the nonexistence of firm-level, market-based policy instruments (Olmstead and Stavins 2008). Key principles regarding the negotiation process of a post-Kyoto agreement are the establishment of a global cap-and-trade approach that connects regional and national tradable permit systems and consequently integrates developing countries. Furthermore, a harmonization of domestic actions to combat climate change should be induced by a portfolio of international treaties and an international adjustment of carbon taxes. Besides the development of a particular climate policy framework, the promotion of technology transfer and reforestation, the reformation of the Kyoto Clean Development Mechanism, and a linkage between global climate policy and global trade policy are inevitable issues of a future arrangement (Aldy and Stavins 2008).

We have also given an economic interpretation of the ideas expressed in the basic mission statement of the Asia-Pacific Partnership on Clean Development and Climate. This partnership intends to promote technology as a way to deal with global environmental problems. Probing deeper, one recognizes that the drivers of all three Schumpeterian phases of technological progress—invention, innovation, and diffusion—are incentives. Promoting clean energy alone with goodwill most likely is not going to be enough as long as fossil energy is cheaper. Therefore, using taxes or trading to make fossil energy more expensive is a way to set an incentive that helps to develop cleaner technology quicker than it would be without such financial incentives. Useful complements to emission taxes and emission permits are subsidies and quantity-based tools that promote technological progress. To our knowledge, no analysis similar to the many studies analyzing optimal emission taxes and permits is available for the subsidies approach.

Existing studies have a hard time incorporating the notion that technology will change over time. More generally, environmental policy, in particular such long-term policy as that related to climate change, has to struggle with the significant uncertainty surrounding benefits, costs, and available technologies. Environmental effects of technologies in development can be estimated but not predicted with certainty. Following the experience of such diverse areas as weather forecasting, horserace betting, macroeconomic variables, and elections we know today that "prediction markets" (where assets are traded and value depends on the probability that a certain event occurs) can play a powerful role in providing effective advice. In particular, they can aggregate information, often more accurately than experts can. While this market could conceivably lead to more volatile emission permit prices, the potential advantages made available by a more effective knowledge and information aggregation mechanism also appear large.

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References

Ackermann BA, Stewart RB (1985) Reforming environmental law. Stanford Law Review 37:1333–1346

Adar Z, Griffin JM (1976) Uncertainty and the choice of pollution control instruments. Journal of Environmental Economics and Management 3:178–188

Aldy J, Stavins RN (2008) Designing the post-Kyoto climate regime: lessons from the Harvard Project on International Climate Agreements. Report for Harvard Project on International Climate Agreements, Belfer Center for Science and International Affairs, Harvard Kennedy School, Cambridge, MA

Barro RJ, Sala-i-Martin X (2003) Economic growth, 2nd edn. MIT Press, Cambridge, MA

Baumol W, Oates WE (1988) The theory of environmental policy. Cambridge University Press, Cambridge, UK
Bennear LS, Stavins RN (2007) Second-best theory and the use of multiple policy instruments. Environmental and Resource Economics 37:111–129
Berg J, Nelson F, Rietz T (2001) Accuracy and forecast standard error prediction markets. University of Iowa, Iowa City
Bessembinder H, Seguin PJ (1992) Futures trading activity and stock price volatility. Journal of Finance 47:2015–2034
Biglaiser G, Horowitz JK, Quiggin J (1996) Dynamic pollution regulation. Journal of Regulatory Economics 8:33–44
Boemare G, Quirion P (2002) Implementing greenhouse gas trading in Europe: lessons from economic literature and international experiences. Ecological Economics 43:213–230
Brown-Hruska S, Kuserk G (1995) Volatility, volume, and the notion of balance in the SP 500 cash and futures markets. Journal of Futures Markets 15:677–689
Bruvoll A, Larsen BM (2004) Greenhouse gas emissions in Norway: do carbon taxes work? Energy Policy 32:493–505
Buscaglia E, van Dijk J (2003) Controlling organized crime and corruption in the public sector. Forum on Crime and Society 3:3–34
Cason TN, Gangadharan L (2003) Transaction costs in tradable permit markets: an experimental study of pollution market designs. Journal of Regulatory Economics 23:145–165
Chen K-Y, Plott CR (1988) Prediction markets and information aggregation mechanism: experiments and application. California Institute of Technology, Pasadena
Chesney M, Taschini L (2008) The endogenous price dynamics of the emission allowances: an application to CO_2 option pricing. Swiss Finance Institute, Zurich
Chichilnisky G, Heal G (1994) Who should abate carbon emissions? An international viewpoint. Economics Letters 44:443–449
Cline WR (2004) Meeting the challenge of global warming. Institute for International Economics, Washington DC
Convery FG (2009) Reflections—the emerging literature on emissions trading in Europe. Review of Environmental Economics and Policy 3:121–137
Cramton P, Kerr S (2002) Tradeable carbon permit auctions: how and why to auction not grandfather. Energy Policy 30:333–345
Dales JH (1968) Pollution, property and prices. University of Toronto Press, Toronto
Darrat AF, Rahman S (1995) Has futures trading activity caused stock price volatility? Journal of Futures Markets 15:537–557
Darrat AF, Rahman S, Zhong M (2002) On the role of futures trading in spot market fluctuations: perpetrator of volatility or victim of regret? Journal of Financial Research 25: 431–444
Daskalakis G, Markellos RN (2008) Are the European carbon markets efficient? Review of Futures Markets 17:103–128
Dewees DN (1983) Instrument choice in environmental policy. Economic Inquiry 21:53–68
Edwards FR (1988a) Does future trading increase stock market volatility. Financial Analyst Journal 44:63–69
Edwards FR (1988b) Futures trading and cash market volatility: stock index and interest rate futures. Journal of Futures Markets 8:421–439
Ellerman AD, Joskow P (2008) The European Union's emission trading system in perspective. Prepared for Pew Center on Global Climate Change, Arlington, VA
Ellerman AD, Montero J-P (2002) The temporal efficiency of SO_2 emissions trading. Center for Energy and Environmental Policy Research (CEEPR) and Catholic University of Chile, Cambridge, MA
Figlewski S (1979) Subjective information and market efficiency in a betting market. Journal of Political Economy 87:75–88
Figlewski S (1981) Futures trading and volatility in the GNMA market. Journal of Finance 39:445–456
Goulder LH (1995) Environmental taxation and the double dividend: a reader's guide. International Tax and Public Finance 2:157–183

Goulder LH, Bovenberg L (1996) Revenue-raising vs. other approaches to environmental protection: the critical significance of pre-existing tax distortions. NBER Working Paper 5641, National Bureau of Economic Research, Cambridge, MA

Gürkayanak R, Wolfers J (2005) Macroeconomic derivatives: an initial analysis of market-based macro forecasts. In: Pissarides C, Frankel J (eds) NBER International Seminar on Macroeconomics, National Bureau of Economic Research, Cambridge, MA

Hahn RW, Stavins RN (2010) The effect of allowance allocations on cap-and-trade system performance. Discussion Paper 10–21, Resources for the Future, Washington DC

Halla M, Schneider F, Wagner AF (2008) Satisfaction with democracy and collective action problems: the case of the environment. University of Linz and University of Zurich

Hanson R (2003) Combinatorial information design. Information Systems Frontiers 5:105–119

Hanson R (2006) Designing real terrorism futures. Public Choice 128:257–274

Harris LE (1989) SP 500 Cash stock price volatilities. Journal of Finance 44:1155–1175

Hutschenreiter G, Aiginger K (2001) Steuerliche Anreize für Forschung und Entwicklung—Internationaler Vergleich und Reformvorschläge für Oesterreich. Austrian Institute of Economic Research (WIFO), Vienna

IPA Energy Consulting (2005) Implications of the EU Emissions Trading Scheme for the UK power generation sector. Prepared for Department of Trade and Industry, London

Intergovernmental Panel on Climate Change (IPCC) (2001) Climate change 2001: impact, adaptation, and vulnerability. Cambridge University Press, New York

IPCC (2007) Climate change 2007: impact, adaptation, and vulnerability. Cambridge University Press, New York

Jacoby HD, Ellerman AD (2004) The safety valve and climate policy. Energy Policy 32:481–491

Jaffe AB, Stavins RN (1995) Dynamic incentives of environmental regulations. Journal of Environmental Economics and Management 29:S43–63

Jaffe J, Stavins RN (2007) Linking tradable permit systems for greenhouse gas emissions: opportunities, implications, and challenges. Prepared for International Emissions Trading Association, Geneva

Jaffe J, Ranson M, Stavins RN (2009) Linking tradable permit systems: a key element of emerging international climate policy architecture. Ecology Law Quarterly 36:789–808

Joskow P, Schmalensee R (1998) The political economy of market-based environmental policy. Journal of Law and Economics 41:37–85

Kemfert C, Praetorius B (2005) The economic costs of climate change and climate change policy (in German). Vierteljahreshefte zur Wirtschaftsforschung. Quarterly Journal of Economic Research 74:133–136

Kohlhaas M (2005) Gesamtwirtschaftliche Effekte der ökologischen Steuerreform (Economic effects of the ecological tax reform). In Diw (ed): Band II für das Vorhaben Quantifizierung der Effekte der ökologischen Steuerreform auf Umwelt, Beshchäftigung und Innovation, Berlin

Kromp-Kolb H (2003) Starting project climate protection – first analysis of extreme weather and its effects in Austria – final report (in German). University of Natural Resources and Applied Sciences Viena

Krupnick AJ, Oates WE, Van de Verg E (1983) On marketable air pollution permits: the case for a system of pollution offsets. Journal of Environmental Economics and Management 10:233–247

Lai Y-B (2008) Auctions or grandfathering: the political economy of tradable emission permits. Public Choice 136:181–200

LaPorta R, Lopez-de-Silanes F, Shleifer A, Vishny R (1999) The quality of government. Journal of Law, Economics and Organization 15:222–279

Lecocq F, Chomitz KM (2001) Optimal use of carbon sequestration in a global climate change strategy: is there a wooden bridge to a clean energy future? Working Paper 2635, World Bank Development Research Group, Washington DC

Lee SB, Ohk KY (1992) Stock index futures listing and structural change in time-varying volatility. Journal of Futures Markets 12:493–509

Lubowski RN, Plantinga AJ, Stavins RN (2006) Land-use change and carbon sinks: econometric estimation of the carbon sequestration supply function. Journal of Environmental Economics and Management 51:135–152

Maeda A (2004) Impact of banking and forward contracts on tradable permit markets. Environmental Economics and Policy Studies 6:81–102
McGartland AM, Oates WE (1985) Marketable permits for the prevention of environmental deterioration. Journal of Environmental Economics and Management 12:207–228
McKibbin WJ, Wilcoxen PJ (2002) The role of economics in climate change policy. Journal of Economic Perspectives 16:107–129
Milliman SR, Prince R (1989) Firm incentives to promote technological change in pollution control. Journal of Environmental Economics and Management 17:245–265
Montero J-P (2002) Prices versus quantities with incomplete enforcement. Journal of Public Economics 85:435–454
Montgomery WD (1972) Markets in licenses and efficient pollution control programs. Journal of Economic Theory 3:395–418
Mukherjee V, Rübbelke DTG (2006) Global climate change, technology transfer and trade with complete specialization. Nota di Lavoro Working Paper 2006.114, Fondazione Eni Enrico Mattei, Milan
Murray BC, Newell RG, Pizer WA (2009) Balancing cost and emissions certainty: an allowance reserve for cap-and-trade. Review of Environmental Economics and Policy 3:84–103
Nelson F, Neumann G, Polgreen P (2006) Operating with doctors: results from the 2004 and 2005 influenza markets. University of Iowa, Iowa City
Newell RG, Pizer WA (2003) Regulating stock externalities under uncertainty. Journal of Environmental Economics and Management 45:416–432
Newell R, Pizer W, Zhang J (2003) Managing permit markets to stabilize prices. Discussion Paper 03-34, Resources for the Future, Washington DC
Nordhaus W (1994) Managing the global commons. MIT Press, Cambridge, MA
Nordhaus W (2006) The Stern Review on the economics of climate change. Yale University, New Haven
Olmstead SM, Stavins RN (2008) A meaningful second commitment period for the Kyoto Protocol. In: Stiglitz JE, Edlin AS, DeLong JB (eds) The economists' voice: top economists take on today's problems. Columbia University Press, New York
Olsson LE, Akiyama M, Gärling T, Gustafsson M, Loukopoulos P (2006) Examining the use of subsidies for the abatement of greenhouse gas emissions through experimental simulations. European Environment 16:184–197
Parsons JE, Ellerman DA, Feilhauer S (2009) Designing a U.S. market for CO_2. Journal of Applied Corporate Finance 21:79–86
Pennock DM, Giles CL, Nielsen FA (2001) The real power of artificial markets. Science 291:987–988
Pizer WA (2002) Combining price and quantity controls to mitigate global climate change. Journal of Public Economics 85:409–434
Roberts MJ, Spence AM (1976) Effluent charges and licenses under uncertainty. Journal of Public Economics 5:193–208
Roll R (1984) Orange juice and weather. American Economic Review 74:861–880
Romer PM (1990) Endogenous technological change. Journal of Political Economy 98:71–102
Santoni GJ (1987) Has programmed trading made stock prices more volatile? Federal Reserve Bank of St. Louis Review 69:8–29
Servan-Schreiber E, Wolfers J, Pennock D, Galebach B (2004) Prediction markets: does money matter? Electronic Markets 14:243–251
Sijm JN, Neuhoff K, Chen Y (2006) CO_2 cost pass through and windfall profits in the power sector. Climate Policy 6:49–72
Snyder LD, NH Miller, RN Stavins (2003) The effects of environmental regulation on technology diffusion: the case of chlorine manufacturing. American Economic Review 93:431–435
Solow RM (1956) A contribution to the theory of economic growth. Quarterly Journal of Economics 70:65–94
Stavins RN (1999) The costs of carbon sequestration: a revealed preference approach. American Economic Review 89:994–1009
Stavins RN (2003) Experience with market-based environmental policy instruments. In: Mäler K-G, Vincent J (eds) The handbook of environmental economics. North-Holland, Amsterdam

Stavins RN (2007) Market-based environmental policies: what can we learn from U.S. experience and related research. In: Freeman J, Kolstad C (eds) Moving to markets in environmental regulation: lessons from twenty years of experience. Oxford University Press, New York

Stavins RN (2008) Addressing climate change with a comprehensive US cap-and-trade system. Oxford Review of Economic Policy 24:298–321

Stavins RN, Richards KR (2005) The cost of U.S. forest-based sequestration. Prepared for Pew Center on Global Climate Change, Arlington, VA

Stein JC (1987) Informational externalities and welfare-reducing speculation. Journal of Political Economy 95:1123–1145

Stern N (2006) The economics of climate change. HM Treasury, London

Svendsen GT (1999) US interest groups prefer emission trading: a new perspective. Public Choice 101:101–128

SwissRe (2006) Results of the global warming: More wind damages in Europe (in German)

Tol RSJ (2006) The Stern Review of the economics of climate change: a comment. Energy and Environment 17:977–981

Uhrig-Homburg M, Wagner M (2009) Futures price dynamics of CO_2 emission allowances: an empirical analysis of the trial period. Journal of Derivatives 17:73–88

van Steenberghe V (2005) Carbon dioxide abatement costs and permit price: exploring the impact of banking and the role of future commitments. Environmental Economics and Policy Studies 7:75–108

Verband der industriellen Energie-u. Kraftwirtschaft (2006) Press release: 10 billion euro unjustified extra profits for the electricity sector (in German)

Weitzman M (1974) Prices versus quantities. Review of Economic Studies 41:477–491

Weitzman ML (2009) On modeling and interpreting the economics of catastrophic climate change. Review of Economics and Statistics 91:1–19

Woerdman E (2001) Developing a European carbon trading market: will permit allocation distort competition and lead to state aid? University of Groningen, Groningen

Wolfers J, Zitzewitz E (2005) Interpreting prediction market prices as probabilities. NBER Working Paper 10359, National Bureau of Economic Research, Cambridge, MA

Wolfers J, Zitzewitz E (2008) Prediction markets in theory and practice. New Palgrave Dictionary of Economics and the Law. Palgrave, London