Using a Policy Mix for Pollution Control – A Review of Economic Literature

Paul Lehmann

Helmholtz Centre for Environmental Research - UFZ Leipzig

May 2008

UFZ-Diskussionspapiere

Department of Economics

4/2008

Using a Policy Mix for Pollution Control – A Review of Economic Literature

*Paul Lehmann**

May 2008

* Helmholtz Centre for Environmental Research – UFZ
Department of Economics
Permoserstr. 15, 04318 Leipzig, Germany

Email: paul.lehmann@ufz.de

Using a Policy Mix for Pollution Control - A Review of Economic Literature

Paul Lehmann

Abstract

This article provides a review of economic studies analyzing the use of multiple policies – a so-called policy mix – to cope with single pollution problems. To guide and structure the review, an analytical framework is developed and applied. The framework integrates transaction costs into the analysis of pollution problems and policies to overcome them. Moreover, it understands a pollution externality not only as a market failure but more generally as the failure of private governance structures. Based on this insight, two rationales for using a policy mix are identified. First, a policy mix may help to correct for multiple reinforcing failures of private governance structures, such as pollution externalities and technological spillovers. Second, a policy mix can be employed if the implementation of single first-best policies brings about high transaction costs – e.g., when marginal pollution damages are heterogeneous or polluters are unlikely to comply with the policy. For each rationale, the relevant literature is presented. Based on the review, avenues for future research are identified.

Key Words: policy mix, review, environmental policy, pollution control, externality, transaction costs, Coase

JEL Classification Numbers: H23, Q53, Q54, Q58

1 Introduction

Pollution control strategies employed by governments used to be based mainly on command-and-control policies. During the last two decades, however, these policies have been supplemented by a variety of new approaches. These include market-based policies, such as taxes, subsidies or permit trading systems, as well as voluntary programs or information measures. As a result of this development, a so-called policy mix is nowadays employed in many countries to cope with single pollution problems (Gunningham and Grabosky 1998; OECD 2007). In many EU Member States, for example, strategies to reduce greenhouse gas emissions are based on a policy mix. The EU Emissions Trading Scheme is complemented by domestic policies such as energy taxes, subsidies for renewable energy sources or measures promoting energy efficiency (Sorrell et al. 2003).

As the number of policies employed to cope with a single pollution problem increases, concerns about the integrity of the policy mix grow. The question arises whether the policy mix has been designed such that it makes use of synergies and avoids contradictions between the different policies – or whether one has to fear "[…] that the policy mix will degenerate into a policy mess" (Sorrell et al. 2003, p. VI).

In traditional environmental economics, the answer to this question would have been clear-cut: Use one policy to mitigate a pollution problem and abolish all others. Economists like Pigou (1920) and Dales (1968) argued that a single tax or tradable permit system corrects for a pollution externality efficiently. They assumed that markets were perfect in other respects and that policies could be perfectly implemented at zero cost. The use of multiple policies was considered a redundancy at best and an inefficient "policy mess" at worst (Johnstone 2003, p. 5). The majority of environmental-economic studies has therefore analyzed the performance of single policies or compared two or more policies for pollution control.

However, there is an emerging field of economic research that discusses rationales for using a policy mix. Studies highlight that in a second-best world – where deviations from the ideal of the perfect market are numerous and policy implementation is subject to a variety of constraints – a policy mix may be superior to single policies in terms of efficiency. Policies applied simultaneously may reinforce each other and compensate for disadvantages of single-policy strategies.

Available economic studies on policy mixes are conducted against a large diversity of backgrounds. On the one hand, they refer to different kinds of pollution problems, such as air pollution, water pollution, climate change or waste management. On the other hand, conclusions in favour of a policy mix are drawn under a variety of different conditions, such as knowledge spillovers or uncertainty. This large diversity raises the demand for a systematic and comprehensive overview of the economic literature on using a policy mix. Moreover, the question arises whether there is a set of general rationales for using a policy mix which overarches the economic literature despite its diversity.

This article provides a review of existing economic studies that bring forward arguments in favour of a policy mix. The studies taken into account focus on situations in which the combination of policies improves the efficiency of resource allocation. The review does therefore not address economic research which finds an existing policy mix to be inefficient. The review aims at a better understanding of general rationales for using a policy mix for pollution control. Moreover, it is meant to identify promising strands for further research.

To guide the review, an analytical framework is developed. It is based on the seminal work by Coase (1960). The framework incorporates transaction costs into the analysis of pollution problems and of possible solutions to overcome them. Moreover, the framework emphasizes that the presence of a pollution externality is not only attributed to a market failure – as widely presumed in economics – but to the failure of private governance structures, including the market, bargains and firms, in general. Based on this insight, it is argued that two deviations from the traditional theoretical model may provide a rationale for using a policy mix. On the one hand, a pollution externality may not exist in isolation but be reinforced by other types of failures of private governance structures, such as technological spillovers and asymmetric information. In this case, multiple policies may be needed to correct all failures simultaneously. On the other hand, a single first-best policy may not be implemented perfectly because the corresponding transaction costs would be too high. A policy mix may then be a useful means to reduce transaction costs. Along these two rationales, the literature review will be organized.

The article is structured as follows: Section two presents the analytical framework. It reflects on Coase's rationale for using regulation. Based on this elaboration, the two rationales for using a policy mix for pollution control are derived. Section three presents the strands of policy mix literature referring to the first rationale. Section four introduces studies related to the second rationale. Section five concludes and highlights possible avenues of future research.

2 Analytical Framework

2.1 Coase's Rationale for Using Regulation

Pioneers in the analysis of environmental problems like Pigou (1920) argued that the presence of pollution externalities and other types of market failures calls for governments to regulate the market to obtain an efficient allocation of resources. Coase (1960) was the first to show that this conclusion was somewhat flawed. He finds that externalities come into being because of transaction costs. Transaction costs have to be considered as well when discussing possible solutions, such as government regulation, to correct for externalities. Based on this finding, Coase concludes that an unambiguous plea for government regulation to correct for externalities cannot be made.

Transaction costs can be broadly defined as the costs of establishing, maintaining and transferring property rights in goods (Allen 1991).[1] In this sense, a transaction is defined as a transfer of property rights (which requires the establishment and maintenance of rights). Coase (1960, pp. 16-17) outlines that transactions can be carried out under different governance structures. On the one hand, transactions can be guided by private governance structures including the market, bargains and firms. On the market, the transfer of property rights is organized decentrally by the pricing mechanism. With bargains in the Coasian sense, property rights are exchanged with individual side payments. In firms, the decentral distribution of property rights is replaced by hierarchical decisions for certain economic activities. On the other hand, transactions can be carried out under public governance structures, such as government regulation.[2] If the government intervenes in the market by regulations, it acts as a "super-firm" that coordinates the transfer and distribution of property rights for the entire society. Coase emphasizes that with none of these governance structures the transfer of property rights is costless. Transaction costs may well differ between governance structures. However, with none of these governance structures transaction costs are per se higher or lower than with another.

Using the insight on transaction costs, Coase (1960, pp. 15-16) explains the presence of pollution externalities in the absence of government regulation. Property rights in natural resources, such

---

[1] To have a property right implies that a person has secure control over a future benefit stream from a good (Bromley 1997, p. 3). Property rights include the rights to use a good and to exclude others from using it, to derive income or utility from a good, to change its form and substance, and to transfer all the rights in the good, or some rights, as desired (Furubotn and Richter 1997, p. 72).

[2] Williamson (1999) further developed Coase's ideas on governance structures. He distinguishes between markets, firms, hybrids of markets and firms (bargains), regulation and public agencies. Regulation and public agencies are both types of public governance structures. With regulation, the government makes private actors carry out certain transactions and produce goods. With public agencies, the government itself produces a good, and all necessary transactions are carried out within the agency. An example for the latter is national defence.

as air or water, may not exist or may not be distributed optimally among private actors under neither private governance structure because the costs of establishing and transferring the rights would exceed the expected benefits. Therefore, many natural resources are non-excludable goods. This may allow some agents to use (and pollute) a natural resource and produce uncompensated damages to other resource users to an extent that is beyond the socially optimal level, i.e. externalities are generated. Thus, pollution externalities persist because under any private governance structure transaction costs of internalizing an additional unit of pollution damage (without government intervention) are higher than the net value of internalization, i.e. the balance of welfare gains from reducing an additional unit of pollution damage and the costs to abate it. The presence of an externality does therefore not only result from a market failure – as widely presumed in economics – but from the failure of private governance structures – including markets, bargains and firms – in general.

According to Coase (1960, p. 18), the failure of private governance structures to correct for pollution externalities is a necessary, but not a sufficient condition for regulation. Governments should only adopt a regulation to internalize a pollution externality if the expected net value of internalization exceeds the transaction costs of setting up and implementing the regulation. The Coasian rationale for using regulation for pollution control can therefore be generalized as follows:

> *A government should implement a regulation if a) the difference D of the net value of internalizing an additional unit of a pollution externality and the transaction costs of bringing it about is positive for regulation and if b) D is larger for regulation than for any private governance structure.*

Suppose that the net value of internalization is the same under each governance structure. Condition b) then requires that the transaction costs of regulation be lower under regulation than under any private governance structure. If the net value of internalizing an additional unit of an externality is below the corresponding transaction costs under government regulation, further internalization by government regulation is not desirable from an economic point of view. In this case, existing pollution externalities can be considered as (Pareto-) irrelevant (Dahlman 1979).[3]

Coase (1960, pp. 17-18) highlights that government intervention may lead to a reduction of transaction costs compared to private governance structures when the problem to solve involves a large number of people – which is the case with most pollution problems such as smoke emis-

[3] Dahlman (1979) even argues that if the government does not do any better than the market (or any other private governance structure), then there is no externality. In this sense, one can only speak of "market failure" (or failure of private governance structures in general) if the market fails to do as well as other governance structures.

sions. Above all, this can be attributed to the government's power of coercion. The government may decide about the establishment, transfer and distribution of property rights, and it monopolizes the forces within a certain territory to enforce its decisions, e.g. by the police. Yet, any government imposing a regulation may also face significant transaction costs, e.g. for determining the appropriate distribution of property rights and monitoring and enforcing the compliance of the regulated parties. Therefore, it cannot be determined on a general level whether or not government regulation provides an efficient means to correct for an externality. Decisions can only be made on a case-by-case basis analyzing transaction costs empirically (Dahlman 1979; Zerbe and McCurdy 1999).

2.2 Rationales for Using a Policy Mix

When discussing the use of regulation, Coase (1960) is not specific about what kind of policies he refers to, and whether there should be one or multiple policies to correct for an externality. Nevertheless, based on his rationale for using regulation, at least two rationales for using a policy mix can be derived. First, if a pollution externality is reinforced by other types of failures of private governance structures, one corrective policy may be needed for each failure. Second, a policy mix may help to correct for a pollution externality where regulation with a single first-best policy would involve (prohibitively) high transaction costs.

2.2.1 Multiple Failures of Private Governance Structures

Pollution externalities may be coupled with and reinforced by failures of private governance structures in other fields. In this case, correcting for the pollution externality only does not necessarily provide for an optimal allocation of resources. Rather, it may be necessary to correct all failures simultaneously by implementing at least one policy for each failure. Two types of failure of private governance structures are of particular importance for environmental pollution problems: Technological spillovers and asymmetric information.[4] Spillovers reinforce pollution externalities in a dynamic perspective while asymmetric information does so in a static perspective.

Technological spillovers are generated by economic actors which innovate and thus contribute to technological change. Spillovers can be considered as positive externalities produced by the innovator (Jaffe et al. 2005). On the market, other actors may benefit from the innovator's knowledge

[4] The coexistence of a pollution externality and market power in the output market theoretically provides another rationale for using a policy mix (Baumol and Oates 1988; Ebert 1992; Gersbach and Requate 2004). An optimal policy mix would encompass a Pigovian tax on pollution and an output subsidy to the monopolist or oligopolist. However, this policy mix is not addressed in this article since it is of little practical relevance. In fact, a regulator will usually have neither the authority nor the inclination to implement a subsidy to firms executing market power (Cropper and Oates 1992, p. 684).

about a new technology without having invested in research and development themselves and without paying compensation to the innovator. This is because knowledge is a public good. An innovator will usually be unable – despite patents – to perfectly protect the knowledge generated by him.[5] Consequently, he may not be able to appropriate the complete social returns of his innovation. His incentives to innovate are reduced to those returns that he can actually realize at the private level. This results in significant underinvestment in R&D, relative to the social optimum. Similarly, knowledge generated when actors adopt new technologies – e.g., by learning-by-doing – may spill over to other market participants as well. Therefore, levels of technology innovation and diffusion under the governance of the market are often too low from a social point of view. The market fails. However, the presence of spillovers implies that other types of private governance fail as well. Actors could form research joint ventures, which pool and coordinate the R&D efforts of several firms (which can be considered as a type of bargain) (Katsoulacos et al. 2001). The innovating firm could also merge with other competitors into one firm (see, e.g., D'Aspremont and Jacquemin 1988). Both approaches would allow the innovator to appropriate more of the social benefits of his innovation. In Coase's (1960) terms, private governance structures fail in correcting spillovers because the transaction costs of defining and transferring property rights in technological knowledge are higher than the net value of reducing spillovers.

Technological spillovers may reinforce pollution externalities positively, i.e. the worse the spillover, the worse the pollution externality. For example, technological spillovers may hamper the development of new and less costly technologies to mitigate pollution externalities. In the future, pollution reduction will be costlier than necessary and the level of the pollution externality will be worse compared to a situation with no technological spillovers.

Asymmetric information is abundant in societies based on the division of labour with principal-agent-relationships. Asymmetric information on markets can be attributed to the public good character of information (Jaffe et al. 2005, p. 168). In order to demonstrate the value of his information, the provider has to reveal at least part of it. Moreover, information may be known to others once it is transferred or used. Other actors may take advantage of the information without compensating the provider for its efforts.[6] Therefore, the possessor of information may not be able to appropriate the total social value information provision brings about (Keck 1987). His

---

5 Patents are a means to prevent spillovers and to protect intellectual property rights. However, Jaffe et al. (2005, p. 168) point out that the rewards the innovator can capture with patents will always be only a fraction of the overall benefits of an innovation to society. Moreover, Katsoulacos et al. (2001, p. 312) highlight that patents reward firms for discovering information but not for sharing it. Thus they provide an incentive to innovate but not to diffuse new technologies.

6 In fact, asymmetric information can therefore be attributed to externalities of information provision. These can be considered positive if an actor is presumed to have the right to conceal information and negative if they have the duty to disclose information.

incentives to reveal information are reduced to his private returns. In fact, these returns may well be zero or negative. For example, if a producer provides information about the bad quality of his products, he will not be rewarded but rather lose clients. The possessor of information may therefore not have an incentive at all to disclose it. Consequently, the provision of information on the market is suboptimal and asymmetric information arises between market participants. The market fails. This failure gives rise to so-called external agency problems (Jaffe et al. 2002, p. 54). Economic actors may make adverse selections. Low-quality goods crowd out high-quality goods, and markets may even collapse (Akerlof 1974). Moreover, actors may use their information advantage and deliberately cheat others to maximize their private utility – a behaviour called moral hazard (see, e.g., Becker 1968). However, the presence of asymmetric information again indicates that not only the market but other private governance structures fail as well. Economic actors could privately initiate labelling and certification systems – which can be considered as one form of bargains. Moreover, information asymmetries could be overcome in a firm. This is an important reason for vertical integration between producers and suppliers (see, e.g., Crocker 1983). However, information asymmetries may also prevail within a firm and cause internal agency problems (Gabel and Sinclair-Desgagné 1998; Jaffe et al. 2002, p. 54). In Coase's (1960) terms, private governance structures fail in correcting for asymmetric information because defining and transferring property rights in information would bring about transaction costs that exceed the net value of reducing asymmetric information.

Asymmetric information may reinforce pollution externalities positively. For example, buyers who have a preference for non-polluting goods may not be able to identify such goods because of asymmetric information between the buyer and the supplier of the good. Buyers are therefore likely to acquire cheaper, but more polluting goods. Consequently, the pollution externality will be worse and correcting it will be costlier than in a situation with perfectly informed market participants.

As has been pointed out before, the failure of private governance structures does not necessarily justify government regulation in each case. Rather, a more complex, first rationale for using a policy mix for pollution control can be derived on this basis:

> *A government should implement a policy mix for pollution control if a) a pollution problem can be attributed to multiple failures of private governance structures which reinforce each other, if b) for each of the failures, the difference D of the net value of reducing an additional unit of the failure and the transaction costs of bringing it about is positive for regulation, and if c) for each of the failures, D is larger for regulation than for any private governance structure.*

If these conditions are met, the optimal policy mix encompasses at least one policy for each type of failure of private governance structures.

2.2.2 High Transaction Costs of Regulation with Single First-Best Policies

Coase (1960) points out that with different governance structures, such as markets, firms or regulation, the net value and the transaction costs of internalizing an additional unit of an externality may differ. Likewise, it can be assumed that transaction costs may vary with different types of regulation, such as command-and-control or market-based policies. These can be understood as different types of public governance structures. For example, different policies may bring about different information requirements for designing a policy and monitoring and enforcing its implementation. With some single first-best policies, the transaction costs of correcting a pollution externality may be very high. Transaction costs may even attain prohibitive levels where they exceed the expected net value of internalization. Alternative single-policy options may provide for lower transaction costs. However, they may not allow for an optimal allocation of resources and thus decrease the net value of internalization. Under certain conditions, combinations of the prohibitively costly first-best policy with further policies or of several alternative policies may then yield a similar net value of internalization as the first-best policy at substantially reduced transaction costs. Thus, a policy mix may be desirable from an efficiency point of view even though only the pollution externality, i.e. only one type of failure of private governance structures is present.

A second rationale for using a policy mix for pollution control is therefore as follows:

> *A government should implement a policy mix for pollution control if a) the difference D of the net value of internalizing an additional unit of the externality and the transaction costs of bringing it about is larger for regulation with a policy mix than for regulation with a single policy, if b) D is positive for regulation with a policy mix, and if c) D is larger for regulation with a policy mix than for any private governance structure.*

Condition a) includes the case where implementing a single first-best policy would involve prohibitively high transaction costs and implementing a policy mix decreases transaction costs such that condition b) is met. It also includes the case where alternative single policies to the first-best policy could be implemented, i.e., D is positive for the single policy, but introducing a policy mix is superior since it increases the net value of internalization and/or decreases the transaction costs of internalization.

3 Using a Policy Mix to Cope with Multiple Failures of Private Governance Structures

The economic literature on using a policy mix to cope with multiple reinforcing failures of private governance structures focuses on cases where a pollution externality coincides with technological spillovers or asymmetric information. It is brought forward that with reinforcing failures of private governance structures, single pollution control policies do not provide for an efficient outcome. Instead, a policy mix may be required to correct for all failures simultaneously and to provide for a superior outcome. Available economic studies usually do not explicitly take the transaction costs of implementing such a policy mix into account. Rather, most studies implicitly assume that the balance of the net value of internalization and corresponding transactions costs is positive for regulation and larger than for any private governance structure. Moreover, most studies consider regulation as a means to correct for market failures while only few explicitly refer to the failures of the firm also.

3.1 Pollution Externalities and Technological Spillovers

3.1.1 Inefficiency of Single Policies

Pollution control policies designed to overcome a pollution externality provide incentives to invest in technological change only to a certain extent. Technological change may allow firms to comply with pollution policies at less cost. For example, firms may reduce their emissions tax burden if they discover new and cheaper technologies for emission reduction. There has been a broad scientific debate on how high these incentives are under different types of pollution control policied. It has been highlighted that market-based policies, such as taxes and tradable permits, are superior to command-and-control policies (Downing and White 1986; Magat 1978; Zerbe 1970). Incentives to foster innovation and diffusion may also vary with market-based policies (Biglaiser and Horowitz 1995; Fischer et al. 2003; Jung et al. 1996; Milliman and Prince 1989). Yet, an unambiguous ranking of policies appears to be impossible (Fischer et al. 2003; Grubb and Ulph 2002).

More importantly, however, the incentives provided by either type of pollution policy are unlikely to be sufficient to overcome technological spillovers. Grubb et al. (1995) highlight that for climate change, the effects of emission mitigation policies may be dominated by technological spillovers. They estimate that the benefits of stimulating and adjusting innovation and diffusion directly may be up to seven times larger than the direct Pigovian benefits from initial emission reductions. Grubb and Ulph (2002) point out that this finding implies that an optimal carbon tax would have to be set far above the level required if only pollution externalities are considered. Grubb and Ulph emphasize, however, that simply raising the level of a carbon tax will provide for inefficiencies as well because not all carbon-reducing investments carry the same potential for long-run innovation. Rather, a more focused stimulation of innovation and diffusion is needed. Thus, pure pollution control policies are not efficient in a dynamic perspective.

3.1.2 Superiority of a Policy Mix

In the presence of pollution externalities and technological spillovers, a combination of pollution policies and technology policies may be superior to the exclusive use of the former. Several authors suggest on a general level to combine tradable permits or taxes correcting for pollution externalities with subsidies addressing the spillovers (Jaffe et al. 2005; Johnstone 2003, p. 22; Sorrell et al. 2003, p. 69). Fischer (2004) argues that the combination of an emissions policy with a strong support for innovation is economically justified if knowledge spillovers are significant. Moreover, she demonstrates that welfare gains from adding a support policy for innovation are particularly high when the emission policy has not been set at a Pigovian level. Analyzing a duopoly with non-cooperative behaviour of firms, Katsoulacos and Xepapadeas (1996) show that the combination of a R&D subsidy and a Pigovian emissions tax may achieve first-best levels of output, emissions and R&D spending. The optimal emissions tax is less than the marginal pollution damage. The optimal level of the subsidy depends on the deviation between the emission tax and the marginal pollution damage, the deviation between the private and social marginal product of R&D and the firms' strategic incentives to invest in R&D.

Katsoulacos et al. (2001) emphasize, however, that the coexistence of a pollution externality and technological spillovers may not call for a policy mix if the assumption of non-cooperative behaviour is relaxed. In fact, research joint ventures may help firms to overcome spillovers. Katsoulacos et al. demonstrate that under certain conditions it may be optimal to have a pollution control policy only and to allow for research joint ventures in addition. Thus, they assume that the balance of the net value of reducing spillovers and the corresponding transaction costs is larger under research joint ventures than under the market, the firm or government regulation. Regulation is only required to correct for the pollution externality.

Jaffe et al. (2005) emphasize that command-and-control policies mandating certain technological standards may also be an appropriate complement to pollution control policies. Command-and-control policies may promote the diffusion of particular technologies by forcing less expensive and less environmentally friendly technologies from the market.[7] As an example, Jaffe et al. cite energy-efficiency regulations in the US, such as the Corporate Average Fuel Economy (CAFE)

[7] Jaffe et al. (2005) acknowledge, however, that such command-and-control policies bear the risk of going beyond an economically justified minimum, at which point they can impose limits to product choice, and undesirable costs if adopters are heterogeneous.

standards. These have been implemented in addition to gasoline taxes in order to improve the fuel efficiency of light-duty vehicles, such as passenger cars and small trucks. Agras and Chapman (1999) provide a rough idea of how such a policy mix may perform compared to the isolated utilization of each policy. They compute that when both policies are used jointly, only 41 percent of the levels determined for the single use of either CAFE standards or gasoline taxes would be necessary to achieve the US reduction targets for greenhouse gases under the Kyoto Protocol.

3.2 Pollution Externalities and Asymmetric Information

3.2.1 Inefficiency of Single Policies

If pollution externalities coincide with asymmetric information, policies that only address the pollution externality may be inefficient at reducing pollution. This is particularly emphasized for the presence of external information asymmetries between market participants. Bennear and Stavins (2007) highlight the case of markets for energy-efficient technologies remaining underdeveloped despite the existence of pollution control policies. Pollution control policies increase energy costs. In theory, agents would have an incentive to switch to energy-efficient technologies, e.g. for domestic appliances or production processes. Yet, agents often do not respond efficiently to pollution control policies because they are not well informed about available options of energy-saving technologies. Jaffe et al. (2002) point out that this is particularly evident in the housing sector. In this sector, the tenant pays for fuel consumed for heating and for electricity. The landlord decides about appliances, such as the insulation of walls and windows or the installation of stoves, which affect the fuel and electricity demand of the tenant. With perfectly informed tenants and landlords, a single emissions tax on fuel or electricity may be efficient. In order to reduce their tax burden, tenants will prefer the most energy-efficient housings. Landlords, in turn, have an incentive to invest in energy-efficient technology. As Jaffe et al. (2005) highlight, however, tenants are hardly informed about the energy efficiency of buildings. Thus, they will be unable to identify the most energy-efficient options. This implies that landlords may be unable to recover the cost of energy-efficiency investments, and may not undertake them at all. Therefore, single emission policies cannot provide for energy-efficiency in the housing sector in the presence of asymmetric information.

Gabel and Sinclair-Desgagné (1998) point out that the efficiency of pollution control policies may also be hampered by internal information problems within the firm. Firms' reactions to pollution control policies are guided by complex, multistep and imperfect management systems. Information transmission from the top management to the simple employee level is characterized by a variety of principal-agent-relationships. The firm's final reaction to a policy – and thus the actual efficiency of a policy – is therefore a function of the incentives and capacities of all agents within the firm and may well deviate from the outcome with rational, profit-maximizing agents.

3.2.2 Superiority of a Policy Mix

The failure of pollution control policies to overcome asymmetric information provides a rationale for combining them with information policies. This is particularly brought forward in the economic literature with respect to external information problems between market participants. Petrakis et al. (2005) argue that information provision may dominate environmental taxation in terms of welfare. They assume that a good produces a pollution externality during production (which does not affect the utility of consumers) and health damages during consumption (which affect utility of consumers). Consumers are not perfectly informed about the health damages resulting from consumption. Information provision then shifts demand to healthier products and at the same time reduces the environmental externality. Consequently, the required level of taxation is reduced and overall welfare increases. A broad body of literature pleads for supplementing pollution control policies by information measures to foster the diffusion of energy-efficient technologies (Bennear and Stavins 2007; Jaffe et al. 2005; Rolfe et al. 1999; Sijm 2005; Sorrell and Sijm 2003). It is argued that additional information measures may help to overcome asymmetric information on the technology market. They provide agents with knowledge about different energy-efficient options. Agents are thus enabled to respond efficiently to the incentives set out by pollution control policies.

Measures to correct for external information problems may be twofold. On the one hand, the regulator may directly provide market participants with information. An example is the US Green Lights program, which provides information on energy-efficient lightning technology to businesses (Bennear and Stavins 2007). On the other hand, the regulator may require market participants to provide information to other market participants by certification or labelling. Producers of domestic appliances may be obliged to display a label on their products indicating the annual energy use and how this energy use compares to other products of the same category – as is done by the EnergyGuide in the United States (Bennear and Stavins 2007). In the housing sector, the landlord may be required to inform the tenant about the energy efficiency of his building, e.g. the level of insulation or the energy consumption of the appliances installed. In the European Union, this approach has been implemented by the energy certificate which has to be issued for each building by the owner (Sunikka 2003). Apart from mandatory information measures, voluntary labelling and certification programs, such as the Energy Star for particularly energy-efficient domestic appliances in the United States, may be implemented to foster the diffusion of energy-efficient technologies (for an overview of existing US programs see Banerjee and Solomon 2003).

Empirical studies on the Green Lights and Energy Star programs suggest that both have been successful at lowering energy consumption (DeCanio 1998; DeCanio and Watkins 1998; Howarth et al. 2000). Sorrell and Sijm (2003, p. 432) argue that it eventually depends on the specific features of the market, the technology and the policies under examination whether or not information policies are a useful component of a policy mix. Sorrell and Sijm expect that information provision will particularly improve the efficiency of pollution policies for households and small and medium-sized firms which are characterized by low energy price elasticity and large energy-saving potential.

Gabel and Sinclair-Desgagné (1998) emphasize that supplementing pollution control policies by further policies may also be useful to overcome problems of internal asymmetric information within the firm. In this respect, they highlight the importance of standards for voluntary environmental management systems such as the International Organization for Standardization's ISO 14001 and the European Eco-Management and Audit Scheme (EMAS).[8] Among other, participating firms are required to set up organizational structures and to define responsibilities and procedures to attain pre-defined environmental goals. Thereby, environmental management systems may improve the flow of environmentally-relevant information within the firm and overcome possible information asymmetries. Other programs have a similar intention. The U.S. Green Lights program requires firms to survey their facilities in exchange for providing them with information on energy-efficient lighting (Bennear and Stavins 2007). The U.S. Department of Energy (DoE) provides free energy audits to small and medium-sized firms that recommend desirable energy-saving projects (Anderson and Newell 2004). The possible effects of these programs have been subject to economic analysis. Anderson and Newell (2004) regard the inexpensive DoE energy audits a success since roughly 50 percent of the suggested projects were actually adopted.[9] Likewise, Wätzold and Bültmann (2001) find that the majority of firms participating in EMAS have reduced the use of polluting materials and have implemented ecologically motivated improvements of products and production processes. They explicitly estimate that the net value of reducing asymmetric information exceeds the corresponding transaction costs (borne by the government) for EMAS. Thus, information measures have proven in many cases to be a desirable complement to pollution control policies from an efficiency perspective.

[8] EMAS can also be understood as a means to overcome external information asymmetries since it requires firms to publish environmental statements. Wätzold and Bültmann (2001) estimate, however, that this effect is limited since EMAS is directed to a specific site or company and not a specific product.

[9] Anderson and Newell (2004) qualify, however, that the fact that 50 percent of the projects were not adopted suggests that asymmetric information is not the only reason for non-adoption.

4 Using a Policy Mix to Cope with High Transaction Costs of First-Best Single Policies

Economic studies highlight that the implementation of single first-best policies for pollution control may bring about high transaction costs under three assumptions: if marginal damages of pollution are distributed heterogeneously, if marginal abatement costs are heterogeneous or if polluters have incentives not to comply with a policy. It is emphasized that with each of these assumptions, transactions costs of a single first-best policy may well be prohibitively high, i.e. exceed the net value of internalizing the pollution externality. It is further demonstrated that the implementation of alternative single policies may reduce transaction costs but usually comes at a decreased net value of internalization as well. The balance of the net value of internalization and transaction costs may be positive for these alternative policies but pollution abatement is likely to be inefficient. The important point brought forward is that a policy mix may then reduce transaction costs and provide for a high net value of internalization. Thus, the balance of the net value of internalization and transaction costs may be positive for the policy mix and larger than for single policies. Available studies implicitly seem to assume that the policy mix also outperforms private governance structures although not much attention is drawn to this question.

4.1 Heterogeneity of Marginal Pollution Damages

4.1.1 Inefficiency of Single Policies

It may be assumed that the spatial distribution of marginal pollution damages is homogeneous, i.e. the marginal damage produced by one pollution unit does not depend on the location of its emission and reception. Homogeneity is provided if pollutants are uniformly mixed in receiving airsheds or watersheds. This applies, for example, to carbon dioxide (CO_2) and chlorofluorocarbons (CFCs). In this case, a pollution externality may be corrected efficiently by a single emission-based policy. For designing such a first-best policy, damages caused by one unit of pollution do not have to be determined by the regulator. Supposed that other transaction costs related to the policy are low as well, it can be set up and implemented easily. The balance of the net value of internalization and related transaction costs is likely to be positive.

However, policy design and implementation become more complex with heterogeneous marginal pollution damages. Heterogeneity arises due to non-uniformly mixed pollutants, such as sulphur dioxide (SO_2), nitrogen oxide (NO_X), and many water pollutants. In these cases, the concentrations – and thus the marginal damages – caused by a pollution unit may vary considerably between locations – depending on ecological, technical, and socioeconomic conditions at the point of emission as well as at the receptor point (Sterner 2003, p. 83).[10] Montgomery (1972) demonstrates that an efficient allocation of pollution units under these circumstances could theoretically be provided for by a single-policy strategy based on "ambient tradable permits", which considers not only emissions but also the damage produced by each unit of pollution. Such permit systems require policy-makers to specify a vector of transfer coefficients for each emitter, linking emissions from each source with concentrations at each of the predefined receptor points. An emitter has to acquire separate pollution permits for each receptor that is affected by its emissions. Krupnick et al. (1983) find that under this first-best permit system, administering agencies incur relatively low transaction costs. Their efforts are limited to specifying the transfer coefficients and allocating permits to polluters. Officials do not need information regarding abatement costs. In contrast, such permit systems result to be very costly for polluters since they have to participate in different permit markets for each receptor point. With many receptor locations, an emitting firm has to acquire and manage a very complex portfolio of necessary permits. Tietenberg (1995) points out that high transaction costs exceeding the expected net values of internalization have prevented first-best ambient permit systems from being implemented. Similarly, Kolstad (1987, p. 340) argues that other spatially differentiated regulations like taxes may also fail due to high transaction costs.

Tietenberg (1995, p. 101) points out the alternative policies taxing or trading heterogeneous pollution units based on the level of emissions rather than on the actual damages of these emissions (e.g., emissions trading or emissions taxes) may bring about relatively low transaction costs but provide for inefficiencies in the presence of heterogeneous marginal pollution damages. Thus, the marginal net value of internalization is reduced. For example, when few large sources are concentrated around a receptor requiring large improvements in ambient air quality, they have to be controlled to a higher degree than distant sources, which hardly affect the receptor. Emission-based policies, however, provide for marginal abatement costs to be equalized across all sources overcontrolling distant sources and undercontrolling adjacent sources. Thus, these approaches may aggravate existing or give rise to new so-called hot spots, where concentrations of pollutants and resulting damages exceed socially optimal levels. Smith (1999, p. 213) highlights that hot spots can affect the efficiency of emission-based instruments particularly negatively if damage functions for pollutants exhibit the characteristics of thresholds and other non-linearities. Under

---

[10] The damages of pollution may vary over time, as well. For example, marginal damages of car emissions in urban areas will peak at daytime when the daily rhythm of the labour market causes congestion and rapid build-up of pollutants to coincide with the highest concentration of people affected. Taking this into account, would make policy design and implementation even more complex.

these circumstances, marginal damages increase substantially once a certain level of pollution is exceeded.

Attempts to improve the efficiency of single emission control policies in the presence of heterogeneous marginal pollution damages, may bring about high transaction costs. One modification that has been developed for emission permit trading makes use of trading zones to prevent hot spots. While trading within each zone is not limited, trading across zones is restricted.[11] Krupnick et al. (1983) and Tietenberg (1995) report that, regarding transaction costs, this approach reverses the findings made for ambient trading schemes. Polluters incur relatively low transaction costs since they only have to participate in the permit market of the zone in which their facilities are located. In contrast, the administering agency has to determine and continuously readjust efficient amounts of permits for each zone. To do so, it must gain knowledge of source-specific abatement costs in addition to the air-modelling data needed for ambient permit system. Moreover, Atkinson and Tietenberg (1982) highlight that zonal systems may provide for inefficiencies in other fields as well since they prevent cost-saving trades between emitting sources in different zones. Thus, zonal trading increases transaction costs but does not necessarily increase the net value of internalization. Consequently, single-policy strategies may not efficiently cope with pollution problems if pollutants are non-uniformly mixed in the environment.

4.1.2 Superiority of a Policy Mix

In the presence of spatially heterogeneous marginal pollution damage, a policy mix combining an emissions tax or an emissions trading scheme with command-and-control policies may be superior to single policies. Regarding a tradable permit system, Krupnick et al. (1983) proposes the approach of "pollution offsets" allowing trading among sources as long as it does not violate ambient air quality standards at any receptor point. New emitters have to acquire permits from existing sources in order to completely "offset" the effects of the new emissions on pollutant concentrations at receptor points. This procedure provides for ambient quality goals to be attained at least cost and is relatively easy to administer. The approach is advanced by McGartland and Oates (1985). They examine "modified pollution offsets" allowing trading among sources if neither the initial level of environmental quality nor certain predetermined ambient standards established by the environmental authority (whichever is more stringent) are exceeded. The approach promises to prevent the costly deterioration of air quality in areas where pollution con-

[11] This approach was pursued in the context of the RECLAIM program, a tradable permit system for NO_X and SO_2 in the Los Angeles basin area. The basin was divided into a coastal and an inland zone. Within each zone, trading is not restricted. However, trades across zones are only allowed if permits are sold from facilities in the heavily polluted coastal zone to facilities in the inland zone (Hansjürgens and Fromm 1996; Tietenberg 1995, p. 107).

centration is already far below ambient air standards. McGartland and Oates show that their approach is cost-effective and achieves a higher level of environmental quality compared to the approach of "pollution offsets". An alternative approach is proposed by Atkinson and Tietenberg (1982). They suggest "nondegradation offsets" that allow trading among sources as long as local ambient air quality standards for the worst receptor are met and the overall emissions do not increase.

Either of the presented approaches combining market-based and command-and-control approaches provides for a second-best solution in the presence of non-uniformly mixed pollutants by sharing tasks between both policies. Baumol and Oates (1988, p. 187) highlight that emission permit systems allow for the reduction of marginal abatement costs across emitting sources. Ambient standards provide for guaranteed minimum benefits due to abatement and prevent hot spots. Compared to the ambient permit system, this approach saves transaction cost since firms are not required to participate in a multitude of separate markets. Compared to a zonal emission permit system, the approach involves only modest information demands on part of the environmental authority.

However, it is emphasized that the actual threat of hot spots and, thus, the actual advantages of a combination of market-based and command-and-control policies over pure market-based policies in terms of efficiency depend on at least two aspects. Firstly, Swift (2001, pp. 349-351; 2004) highlights that the relationship between the spatial distribution of marginal damages and the spatial distribution of marginal abatement costs appears to be important. Swift's empirical examination of the US Acid Rain Program for sulphur dioxide emissions suggests that marginal abatement costs were lowest for the largest polluters. These polluters had the highest incentives to reduce their emissions under the emissions trading system. Thus, emissions trading abated pollution at the most heavily emitting sources first and rather "cooled" existing hot spots instead of exacerbating them. Secondly, Portney (2000, p. 118) and Swift (2000) report for the example of the Acid Rain Program that the implementation of market-based emissions policies may provide incentives to reduce emissions substantially at all existing sources. Thus, even given spatial reallocations of emissions, pollution at hot spots everywhere will be reduced.

4.2 Heterogeneity of Marginal Pollution Abatement Costs

4.2.1 Inefficiency of Single Policies

Price-based policies (such as taxes) and quantity-based policies (such as tradable permits) provide for efficient pollution control if the price or quantity for pollution set under each policy, respectively, matches the intersection of the marginal abatement cost curve and the marginal damage cost curve. Determining the marginal abatement cost curve is easy for the regulator if the costs of abating one unit of pollution are the same no matter by whom, where and when this is done. However, marginal pollution abatement costs are usually characterized by large heterogeneity. Polluters exhibit differences in the technologies they employ, the inputs they use, and the outputs they produce, all of which may have an effect on the direct and opportunity costs of pollution abatement. In order to determine the aggregated marginal abatement cost curve, the regulator has to find out about the characteristics of each polluter. Designing a first-best price-based or quantity-based policy may thus bring about significant transaction costs (Sterner 2003, p. 165). Kwerel (1977) shows that, in theory, a regulator could learn about the true abatement costs by successively implementing and revising policies based on polluters' responses to the policies. However, Bennear and Stavins (2007) point out that the marginal abatement cost curve may shift over time as well, for example, because of technological progress or changes in input and output prices. Thus, an iterative approach does not necessarily reduce the information demand for the regulator.[12]

If transaction costs impede a correct assessment of heterogeneous marginal abatement costs, regulators may choose to accept a certain degree of uncertainty regarding abatement costs and rely on more or less rough estimates. Under these circumstances, the implementation of price-based policies as well as of quantity-based policies is likely to result in inefficient over- or under-regulation. If, on the one hand, marginal abatement costs turn out to be lower than expected, the quantity restriction, which appeared to be optimal ex ante, will be not stringent enough compared to the social optimum resulting in too little abatement, whereas the tax chosen ex ante will be too high causing too much abatement. On the other hand, if marginal abatement costs prove to be higher than expected the reverse will be true: Abatement levels will be too high under the quantity policy and too low under the tax (Johnstone 2003, p. 15). Thus, reducing transaction costs comes at the expense of a reduced net value of internalization.

Weitzman (1974) demonstrates that price-based and quantity-based policies are not equally inefficient in the presence of uncertain abatement costs, i.e. the costs of overregulation by one policy do not exactly correspond to the costs of underregulation by the other. He finds that deadweight losses are smaller under a price-based policy than under a quantity-based policy if the slope of the (expected) marginal abatement cost function is greater than the (absolute value of the) slope of the marginal benefit function (the inverse of the marginal damage function). Correspondingly, the quantity-based policy is less inefficient than the price-based policy if the marginal benefit func-

[12] Moreover, a lot of investment decisions related to pollution abatement are long-term and cannot be reversed easily by policy revisions (Bennear and Stavins 2007).

tion is steeper than the marginal abatement cost function. Applying Weitzman's finding to climate change, Pizer (1999; 2002) shows that price-based policies should be preferred since the marginal damages curve of carbon dioxide emissions is rather flat. Hoel and Karp (2001) and Newell and Pizer (2003) confirm this finding for a dynamic context where the marginal damage of emissions is a function of the stock of pollutants accumulated over time. Nevertheless, a policy mix may be superior to both price-based and quantity-based policies, i.e. provide for a higher net value of internalization, irrespective of the assumptions about marginal cost and benefit curves.

4.2.2 Superiority of a Policy Mix

Roberts and Spence (1976) demonstrate that the combination of quantity-based and price-based policies provides for a better outcome in terms of social costs than either policy individually. They propose a permit trading system which is supplemented by taxes and subsidies.[13] Their three-part policy combines the advantages of price-based and quantity-based policies and compensates for their deficiencies. On the one hand, the tax protects against unexpectedly high permit prices if true marginal abatement costs are higher than anticipated and a pure permit trading system would result in too much abatement. The mechanism works as follows: The regulator allows polluters to generate emissions in excess of their permit holdings but charges a tax per unit of such emission (or requires polluters to buy additional permits from the regulator at a fixed price). If the permit price actually rises above the tax rate, polluters with even higher marginal abatement costs will choose to pay the tax rather than buy permits on the market. Hence, the tax acts as a "safety valve" that caps the permit price and prevents inefficiencies due to extraordinary price increases.[14] On the other hand, subsidies may stimulate further abatement if marginal abatement costs are lower than expected and a pure permit trading system would result in too little abatement.[15] In order to do so, the regulator pays firms for every unit of pollution that falls below their actual permit holdings. The subsidy sets a floor for the permit price since any polluter will rather collect this payment than sell his permits on the market at a lower price. Within this price range, the permit system provides for the attainment of the pollution reduction target determined ex ante. Thus, such three-part policy sets binding emission targets as long as costs are

---

[13] See also Weitzman (1978).

[14] Similarly, a regulator can also provide for cost certainty by creating a permit reserve which he can bring on the market in the case of unexpectedly high permit prices. This approach has the disadvantage, however, that the price can only be capped for as long as the permit reserve holds (Johnstone 2003, p. 17). Jacoby and Ellerman (2004) mention that price certainty under a permit trading scheme can be provided for by banking and borrowing provisions as well – however not to the same extent as by a safety valve.

[15] Baumol and Oates (1988, pp. 222-223) demonstrate, however, that subsidizing firms for pollution abatement involves dynamic inefficiencies.

reasonable and allows the target to rise (tightens the target) if costs are unexpectedly high (low). Similarly, Smith (1999, p. 212) suggests to implement taxes and subsidies as a supplement to command-and-control policies, which guarantee quantity, but at uncertain abatement cost.

The use of a safety valve has been examined particularly for the context of climate change policies. Fearing high costs of carbon abatement that may even exceed its benefits, McKibbin and Wilcoxen (1997a; 1997b) suggest an international agreement on climate change establishing a system that combines national emission permits and fees.[16] According to their approach, each country would be allowed to allocate emission permits equal to its 1990 carbon emissions, and would agree to sell additional permits at a fee specified in the agreement. They propose an internationally uniform initial fee of US$ 10 per ton of carbon. Kopp et al. (1997; 1999) focus on designing a domestic permit trading scheme for greenhouse gas emissions in the United States in the presence of abatement cost uncertainty. They suggest the allocation of permits for the emission of 1,460 million tons of carbon (this corresponds to the actual carbon emissions in the US in 1996) and a price cap of US$ 25 per ton of carbon. With respect to a global climate change policy, Pizer (2002) finds that the hybrid approach performs slightly better than the price-based approach but considerably better than the quantity-based approach. An optimal hybrid policy would set a global carbon emission target of 5 gigatons and a safety valve of US$ 7 per ton of carbon emission. Jacoby and Ellerman (2004) emphasize that national safety valves may impair the operation and efficiency of an international permit trading scheme. If the safety valve in one country is set below the clearing price on the international permit market, polluters will rather buy their permits at the domestic safety valve price than on the international permit market. The lowest national price cap would therefore determine the international permit price.

4.3 Non-Compliance by Polluters

4.3.1 Inefficiency of Single Policies

As Cropper and Oates (1992) point out, it is often assumed in economic literature that firms and individuals comply perfectly with pollution policies they are subject to. For example, firms are supposed to keep their emissions within the limitation prescribed under a standard or to accurately report their emissions and pay the required fees. The policy does not bring about transaction costs since the regulator does not have to invest resources in monitoring and enforcement.

---

[16] Apart from high abatement costs, McKibbin and Wilcoxen especially fear that a pure permit trading system on an international level would result in inacceptably high wealth transfers from developed to developing coutries, that it would put enormous stress on the world trade system, that it would be inoperable due to the allocation of excess permits, particularly to countries of the former Soviet Union, and that it would be difficult to monitor and enforce.

Under otherwise perfect conditions, a single first-best policy can be implemented to correct for a pollution externality.

However, Becker (1968) highlights that individuals may have an incentive not to comply with regulation. This incentive arises because pollution policies usually bring about additional costs for the individual (either for abatement measures or tax payments and permit purchases), which can be avoided by non-compliance (Gersbach 2002).[17] Consequently, the regulator has to incur transaction costs for the proper monitoring and enforcement of a pollution policy. Transaction costs rise with the level of information asymmetry between the regulator and the individuals (Sterner 2003, p. 106). Moreover, Bohm and Russell (1985) emphasize that monitoring and enforcement costs are particularly high with numerous and mobile sources of pollution polluters. This applies, for example, to waste disposal and car emissions. Reducing monitoring and enforcement efforts to bring down transaction costs comes at rising costs of non-compliance. Fullerton and Kinnaman (1995) state, for example, that the illegal disposal or burning of waste in order not to pay a tax on garbage may even deteriorate the pollution problems related to waste and produce new externalities. Palmer and Walls (1997) make the point that the costs of monitoring and enforcement, or the costs due to non-compliance, may (partly) outweigh or even exceed the net value of reducing pollution, i.e. implementing the policy may not be advisable from an efficiency point of view. Downing and Watson (1974) demonstrate that with positive enforcement costs, the optimal level of pollution abatement will be less than when these costs are ignored.

If monitoring and enforcing a first-best direct regulation on a polluting good is very costly, policy-makers may bring down transaction costs by regulating related goods that are easier observable.[18] Eskeland and Jimenez (1992) point out that the intuitive suggestion is to tax complements to a polluting good and subsidize cleaner substitutes. For example, if it is too costly for a regulator to monitor and enforce a direct tax on car emissions, he may choose to tax fuels (complementary input to car emissions) or to subsidize catalysers or public transportation (substitutes to car emissions). If the regulator faces difficulties in implementing a tax on waste disposal, he may likewise tax packaging or consumption in general or subsidize returning and recycling waste. Subsidies bear the additional advantage that they provide incentives to disclose information (e.g. a polluter may only receive a subsidy if he provides adequate evidence of recycling) and increase

---

[17] However, the actual extent of non-compliance is debatable. Harrington (1988) points out that substantial compliance may exist in spite of only modest monitoring and enforcement efforts.

[18] Several authors point out that in order to bring down monitoring and enforcement costs, the regulator may also increase fines (see, e.g., Becker 1968) or implement differentiated monitoring and enforcement systems (see, e.g., Harrington 1988).

the utility of compliance by reducing the cost of pollution abatement (e.g. by subsidizing abatement technologies or appropriate waste disposal).

In spite of reducing the cost of monitoring and enforcement and non-compliance, these policies do not necessarily provide for cost-minimizing pollution abatement – and thus decrease the net value of internalization – if implemented in isolation.[19] Inefficiencies arise because indirect taxes and subsidies do not perfectly mimic the substitution and output reduction effects that provide for efficient resource allocation under a direct tax (see, e.g., Fullerton and Wolverton 1999). Eskeland and Jimenez (1992, p. 155) point out that the taxation of dirty inputs to the production of polluting goods, such as fuels, provides incentives to switch to cleaner inputs and to reduce the production of a good. However, it does not stimulate polluters to employ potentially cheap technologies to reduce emissions with dirty inputs, e.g. catalytic converters or scrubbers. Taxing dirty technologies, in turn, does neither provide incentives to switch fuels nor guarantee the proper maintenance of cleaner alternatives. Alternatively, the regulator may tax the output or consumption of related goods. Palmer et al. (1997) point out that the taxation of disposable goods – instead of their actual disposal – reduces waste disposal since it discourages their consumption. However, it fails to stimulate waste reduction by recycling and the use of recycled inputs rather than virgin inputs. In fact, Palmer et al. find that the overall amount of recycling will decline with decreasing consumption.

Subsidies to clean inputs, such as low-emission fuels, pollution abatement technologies, and recycled resources, or on clean activities, such as recycling, stimulate substitution processes but lack sufficient output reduction effects. For example, Palmer et al. (1997) state that a subsidy to recycling sets an incentive to substitute virgin inputs. Yet, they highlight that the subsidy may encourage consumption and thus waste generation because it reduces the effective price of a potentially polluting good for users. This finding has been made for the case of direct subsidies for pollution abatement as well. Several authors emphasize that subsidies will be inefficient in this context because they will foster the entry of new polluters, which in turn increases overall production, consumption and pollution (Baumol and Oates 1988; Kohn 1991; Porter 1974).

4.3.2 Superiority of a Policy Mix

If monitoring and enforcing first-best direct pollution control policies is very costly and indirect policies bring about inefficiencies in pollution abatement, the implementation of a policy mix

[19] Moreover, Sandmo (1976) and Wijkander (1985) emphasize that taxing complements and subsidizing substitutes may result in inefficient distortions in a general equilibrium framework if complements and substitutes are related to other, non-polluting goods as well, or if the demand for complements and the demand for substitutes are related to one another.

may be a superior strategy. In particular, it may be useful to combine indirect taxes and subsidies. As Bohm (1981) makes clear, the classic application of this concept is the deposit-refund system.[20] At some point in the chain of market transactions, a potential polluter is subjected to a tax (the deposit) in the amount of the potential damage he may produce, which he has to pay under the presumption that the pollution and the related damage actually occur. At a later point, he receives a subsidy (the refund) if certain conditions are met, e.g. if he can prove that a certain product has been returned to specified place or that a specified type of damage has not occurred. Bohm and Russell (1985) point out that deposit-refund systems can be implemented for the consumption of products which may create pollution damages, e.g. beverage containers, mercury and cadmium batteries, refrigerators, vehicles, or waste in general, and production processes potentially providing for hazardous emissions of chemicals or the disposal of toxic wastes.

Deposit-refund systems combine the advantages of single indirect taxes and subsidies and compensate for their disadvantages. Fullerton and Wolverton (1999) and Yohe and MacAvoy (1987) highlight that deposit-refund systems provide for a substantial reduction in transaction costs compared to direct pollution control policies since costly monitoring of pollution is avoided. What is more, deposit-refund systems do not exhibit the inefficiencies of indirect taxes and subsidies with respect to pollution abatement costs. In fact, Fullerton and Wolverton (1999) show that a deposit-refund system may perfectly mimic a first-best Pigovian tax on pollution. The tax component provides for an optimal reduction of output, while the subsidy component efficiently stimulates substitution of dirty goods and activities by cleaner ones. Thus, the policy mix provides for a high net value of internalization at relatively low transaction costs.

There is a large body of literature discussing the use of deposit-refund systems to reduce waste generation and its illegal disposal. Dinan (1993) demonstrates that the combination of a tax on goods that may eventually be disposed and a subsidy to end-users of recycled materials is equivalent to a waste-end tax and performs better than a tax on virgin inputs. Fullerton and Kinnaman (1995) suggest a combination of a tax on output and a rebate on proper disposal through either recycling or garbage collection. They point out that this policy mix may yield a first-best outcome and outperforms single output taxes or recycling subsidies. Their finding is supported by Palmer et al. (1997) who compute that single-policy alternatives may be at least twice as costly as the proposed deposit-refund system. In addition, Palmer and Walls (1997) show that the combination of an output tax and a recycling subsidy exhibits an efficiency that is far above that of recy-

[20] Bohm (1981) distinguishes between government-initiated and market-initiated deposit-refund systems. Since the focus of this paper is on using a policy mix, we only discuss government-initiated deposit-refund systems. However, the existence of market-initiated deposit refund systems demonstrates that pollution externalities can also be corrected by governance structures other than the market if only the private benefits of doing so are high enough.

cled content standards, which require that a certain percentage of total material use be comprised of secondary materials. The same finding is made by Sigman (1995) for the special case of lead disposal. Walls and Palmer (2001) extent the analysis of this type of deposit-refund systems to a setting with multiple lifecycle externalities. They show that under these circumstances, the optimal tax on output will be greater than the optimal subsidy for recycling. An alternative deposit-refund system is brought forward by Fullerton and Wu (1998). They highlight that the combination of a tax on packaging with a subsidy to recyclability of goods may provide for an optimal resource allocation as well. On a more general level, Fullerton and Wolverton (2005) analyse how deposit-refund systems can yield an optimal outcome in a second-best world with pre-existing tax distortions.

A case for the use of deposit-refund systems is also made with respect to air pollution. Regarding car emissions, Fullerton and West (2000) show that the combination of a tax on gasoline and a subsidy to newer cars can attain 71 percent of the welfare gain of a Pigovian emissions tax, whereas a tax on gasoline alone will only yield 60 percent. With respect to emissions from stationary sources, Porter (1974) and Kohn (1991) discuss the combination of a periodical "entry tax" – by which the polluter purchases the rights to produce and emit and which is based on prospected baseline emissions of production in the absence of emission abatement – with a subsidy per unit of emission that is actually abated during the period. This approach is efficient and makes cheating more risky since emission reports may be double-checked with reported abatement. While Porter rejects his idea as impractical, it is revived by Kohn who states that the emission data required is already researched and published by the U.S. Environmental Protection Agency. A similar proposal is made by Yohe and MacAvoy (1987). They suggest combining a tax on the sulphur content of coal used in production with a subsidy for proven removal of sulphur from the industrial effluent and show that this two-part policy yields a first-best outcome. A different approach is pursued by Swierzbinski (1994). He develops a system in which the firm has to report its emissions and pays an initial tax based on this report. If the firm is monitored, it receives a subsidy if actual emissions turn out to coincide with reported emissions. Whether or not this system is efficient depends among other on the limitations to enforcement.

A somewhat concluding point on the applicability of deposit-refund systems is made by Fullerton and Wolverton (1999). They emphasize that the idea of this two-part policy can be transferred to a very general level. The refund may be paid to an individual other than the one who paid the deposit, the optimal refund may be a different amount than the deposit, and refund and deposit may even refer to different commodities.

Alternatively to deposit-refund systems, some authors suggest combinations of taxes and standards. For stationary emission sources, Walls and Palmer (2001) demonstrate that in order to provide for a first-best outcome, an output tax has to be combined with a standard that limits emissions per unit of output. Likewise, an input tax should be supplemented by an emission standard per unit of input. Eskeland (1994) highlights that when car emissions cannot be observed directly, the simultaneous implementation of a tax on gasoline and an emission abatement requirement for cars performs better than the isolated use of either policy. The policy mix mimics the incentives of a first-best direct emissions fee since the gasoline tax provides for fewer miles driven while the abatement standard reduces the emissions per mile driven. Similarly, Innes (1996) suggests gasoline taxation and automobile standards. As an alternative to the latter component, he discusses the taxation of automobiles. He recommends that this should be imposed in relation to vehicle features that affect emissions, such as fuel economy or vehicle age. The optimal automobile tax equals the social costs of the vehicle's predicted emissions, less the portion of these costs that are internalized by the gasoline tax.

Apart from using mixes of indirect policies, some studies also propose to supplement direct policies for pollution control by further policies in order to overcome problems of monitoring and enforcement. Johnstone (2003, p. 17) suggests to combine an emissions trading scheme with a punitive tax which has to be paid per unit of emission which is not covered by emission allowances. Like a fine, the tax reduces incentives for non-compliance by diminishing its expected utility, and thus reduces monitoring requirements for the regulator. Gawel (1991; 1993, p. 12) and Knorring and Welzel (1998) highlight that compliance with standards may also be improved by punitive taxes. Similarly, rules to hold firms liable for potential damages from their pollution may improve compliance with pollution control policies. Bohm and Russell (1985, p. 435) emphasize that liability rules may be particularly useful if monitoring polluting activities is expensive but the source of discharges and spills can be easily identified ex post. Schwarze (1995) demonstrates that liability fosters the enforcement of pollution standards even when the compensation to be paid by the polluter can be expected to be below the actual damage from pollution. Nevertheless, Eskeland and Jimenez (1992, p. 159) state that low likelihood of detection, high costs to victims for representation and litigation, underdeveloped judicial processes, or the potential insolvency of a liable party may limit the usefulness of liability rules in addition to pollution policies.

5 Conclusion

There is an increasingly large body of economic literature discussing the use of multiple policies – a so-called policy mix – to cope with single pollution problems. This article provides a review of studies in this field. To guide and structure the review, an analytical framework is developed and applied. Based on seminal work by Coase (1960), the framework integrates transaction costs into the analysis of environmental problems and policies to overcome them. Moreover, it is highlighted that pollution externalities come into being not only because the market fails but due to the failure of private governance structures – including the market, bargains and firms – in general. Two basic rationales are derived which underlie the economic literature on using a policy mix. On the one hand, it may be necessary to combine policies to correct for multiple reinforcing failures of private governance structures, such as pollution externalities, technological spillovers and asymmetric information. On the other hand, a policy mix may be used if the implementation of single first-best policies brings about high transaction costs – e.g., when marginal pollution damages and marginal abatement costs are heterogeneous or polluters are unlikely to comply with a policy. Available studies provide a broad picture of how a policy mix may help to improve efficiency compared to single policy strategies. The general rationales identified may also provide useful guidance for understanding, evaluating and possibly justifying an actually implemented policy mix, as it can be found throughout many countries.

Nevertheless, the framework is also useful to identify limitations of available economic research on using a policy mix. These limitations may open up avenues for future research. First of all, the economic literature drawing on the rationale of using a policy mix to correct for multiple reinforcing failures of private governance structures typically neglects transaction costs of policy implementation – or rather assumes that these are sufficiently low. Yet, the second part of this review has demonstrated that this cannot be taken for granted. Future research in this field therefore has to consider the transaction costs coming along with the policy mix as they may preclude the use of certain policies in the mix or of regulation in general.

Secondly, most studies on policy mixes do not reflect on the use of private governance structures rather than regulation. This seems to be straightforward since pollution externalities, technological spillovers and asymmetric information can be considered as a failure of private governance structures. Yet, this failure may stem from institutional, including regulatory, constraints. It may be worthwhile to explore what these constraints are and whether modifying or abolishing some of them may allow for private solutions that are superior to regulation in terms of efficiency. It has been pointed out, for example, that if pollution externalities are reinforced by externalities of technological change, research joint ventures can do as well as technology subsidies in supplementing emission policies under certain conditions (see Katsoulacos et al. 2001). The only requirement with respect to regulation would be to allow for research joint ventures. Likewise, it may be promising to test for the potential of, e.g., private certification and labelling agreements to overcome asymmetric information or privately initiated deposit-refund systems to avoid the monitoring problems of single pollution policies. There may be instances where supporting such private schemes is more efficient than implementing government-initiated programs.

Thirdly and more generally, available studies on policy mixes are often conducted on a rather abstract, theoretical level. The incorporation of transaction costs into the analysis of a policy mix for pollution control calls for more empirical work. As Zerbe and McCurdy (1999) point out, it can only be determined on a case-by-case basis what the actual transaction costs are and whether a policy mix should be implemented or not. In order to provide for reliable recommendations, future analyses have to take into account a variety of aspects determining the level of transaction costs, such as the characteristics of the environmental resources, of the resource users, of the transactions taking place and of the institutional environment all of them are embedded in.

As a fourth limitation, existing studies usually analyze the combination of policies with idealized and simplified designs. However, policies that are actually implemented are often far from matching the theoretically ideal design. For example, policies may account for special rules for certain stakeholder groups. The actual design may well impair the theoretical efficiency of the policy mix, i.e. reduce the net value of internalization or increase transaction costs. Economists intending to give advice to policy-makers will therefore have to consider the actual design of the policy mix.

Finally, studies presented in the review analyze how an optimal policy mix should theoretically look like under certain assumptions. Yet, it may well turn out that a policy mix exists in reality although none of presented rationales applies – or that no policy mix has been implemented despite economic insight to do so. In order to provide for applicable economic policy recommendations, further research is necessary analyzing how an existing policy mix has actually come about in a certain context. Policy-makers are subject to a variety of constraints and incentives that guide their decisions. For example, regulatory decisions on policies for pollution control may be taken at multiple levels, e.g., by the EU and national governments. The responsibilities of different levels may overlap and result in simultaneous policy-making. In addition, policy-makers may be influenced by multiple stakeholders of the policies with possibly contrary interests. Moreover, policy-makers usually do not only pursue environmental and efficiency goals but other, potentially contradictory ones as well, such as equity. Only if these constraints are taken into account, reasonable recommendations for the design and implementation of an optimal policy mix can be derived. It may be one result of this positive analysis, that the existing policy mix exhibits inefficiencies but represents the optimal choice if all constraints are considered. It may be another result, that in order for a superior policy mix to be implemented, some of the constraints have to be eliminated or changed.

Acknowledgments

The author is grateful to Dallas Burtraw, Ines Dombrowsky, Frank Wätzold and many colleagues at the Helmholtz Centre for Environmental Research – UFZ, Leipzig, and Resources for the Future (RFF), Washington, DC for their numerous and very helpful comments. Research for this paper has been funded by the Stiftung der Deutschen Wirtschaft (sdw).

References

Agras, J., and Chapman, D. (1999). "The Kyoto Protocol, CAFE Standards, and Gasoline Taxes." *Contemporary Economic Policy*, 17, 296-308.

Akerlof, G. (1974). "The Market for Lemons: Quality Uncertainty and the Market Mechanism." *The Quarterly Journal of Economics*, 84, 488-500.

Allen, D. W. (1991). "What are Transaction Costs?" *Research in Law and Economics*, 14, 1-18.

Anderson, S. T., and Newell, R. G. (2004). "Information programs for technology adoption: the case of energy-efficiency audits." *Resource and Energy Economics*, 26, 27-50.

Atkinson, S. E., and Tietenberg, T. (1982). "The Empirical Properties of Two Classes of Designs for Transferable Discharge Permit Markets." *Journal of Environmental Economics and Management*, 9, 101-121.

Banerjee, A., and Solomon, B. D. (2003). "Eco-labeling for energy efficiency and sustainability: a meta-evaluation of US programs." *Energy Policy*, 31, 109.

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

Becker, G. S. (1968). "Crime and punishment: an economic approach." *Journal of Political Economy*, 86, 169-212.

Bennear, L. S., and Stavins, R. N. (2007). "Second-Best Theory and the Use of Multiple Policy Instruments." *Environmental and Resource Economics*, 37, 111-129.

Biglaiser, G., and Horowitz, J. K. (1995). "Pollution Regulation and Incentives for Pollution-Control Research." *Journal of Economics and Management Strategy*, 3, 663-684.

Bohm, P. (1981). *Deposit-Refund-Systems: Theory and Applications to Environmental, Conservationn and Consumer Policy*, Johns Hopkins University Press for Resources for the Future, Baltimore, MD.

Bohm, P., and Russell, C. (1985). "Comparative analysis of alternative policy instruments." Handbook of Natural Resource and Energy Economics, A. V. Kneese and J. L. Sweeney, eds., Elsevier, Amsterdam, 395-460.

Bromley, D. W. (1997). "Property Regimes in Environmental Economics." The Internation Yearbook of Environmental and Resource Economics 1997/1998, H. Folmer and T. Tietenberg, eds., Edward Elgar, Cheltenham, UK, 1-27.

Coase, R. H. (1960). "The Problem of Social Cost." *Journal of Law and Economics*, 3, 1-44.

Crocker, K. J. (1983). "Vertical Integration and the Strategic Use of Private Information." *The Bell Journal of Economics*, 14, 236-248.

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

D'Aspremont, C., and Jacquemin, A. (1988). "Cooperative and Noncooperative R&D in Duopoly with Spillovers." *American Economic Review*, 78, 1133-1137.

Dahlman, C. J. (1979). "The Problem of Externality." *Journal of Law and Economics*, 22, 141-162.

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

DeCanio, S. J. (1998). "The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments." *Energy Policy*, 26, 441-454.

DeCanio, S. J., and Watkins, W. E. (1998). "Investments in Energy Efficiency: Do the Characteristics of Firms Matter?" *The Review of Economics and Statistics*, 80, 95-107.

Dinan, T. (1993). "Economic Efficiency Effects of Alternative Policies for Reducing Waste Disposal." *Journal of Environmental Economics and Management*, 25, 242-256.

Downing, P. B., and Watson, W. D. (1974). "The Economics of Enforcing Air Pollution Controls." *Journal of Environmental Economics and Management*, 1, 219-236.

Downing, P. B., and White, L. J. (1986). "Innovation in Pollution Control." *Journal of Environmental Economics and Management*, 13, 18-29.

Ebert, U. (1992). "Pigouvian Tax and Market Structure: The Case of Oligopoly and Different Abatement Technologies." *Finanzarchiv*, 49, 154-166.

Eskeland, G. (1994). "A presumptive Pigovian tax: complementing regulation to mimic an emissions fee." *The World Bank Economic Review*, 8, 373-394.

Eskeland, G., and Jimenez, E. (1992). "Policy Instruments for Pollution Control in Developing Countries." *The World Bank Research Observer*, 7, 145-169.

Fischer, C. (2004). "Emissions Pricing, Spillovers, and Public Investment in Environmentally Friendly Technologies." *RFF Discussion Paper* 04-02, Resources for the Future (RFF), Washington, D.C.

Fischer, C., Parry, I. W. H., and Pizer, W. A. (2003). "Instrument Choice for Environmental Protection When Technological Innovation is Endogenous." *Journal of Environmental Economics and Management*, 45, 523-545.

Fullerton, D., and Kinnaman, T. (1995). "Garbage, recycling, and illicit burning or dumping." *Journal of Environmental Economics and Management*, 29, 78-91.

Fullerton, D., and West, S. E. (2000). "Tax and Subsidy Combinations for the Control of Car Pollution." *NBER Working Paper* 7774, National Bureau of Economic Research, Cambridge, MA.

Fullerton, D., and Wolverton, A. (1999). "The Case for a Two-Part Instrument: Presumptive Tax and Environmental Subsidy." Environmental and Public Economics: Essays in Honor of Wallace E. Oates, A. Panagaria, P. R. Portney, and R. Schwab, eds., Edward Elgar, Cheltenham, UK, 32-57.

Fullerton, D., and Wolverton, A. (2005). "The two-part instrument in a second-best world." *Journal of Public Economics*, 89, 1961-1975.

Fullerton, D., and Wu, W. (1998). "Policies for Green Design." *Journal of Environmental Economics and Management*, 36, 131-148.

Furubotn, E. G., and Richter, R. (1997). *Institutions and Economics Theory: The Contribution of the New Institutional Economics*, The University of Michigan Press, Ann Arbor.

Gabel, H. L., and Sinclair-Desgagné, B. (1998). "The firm, its routine and the environment." International Yearbook of Environmental and Resource Economics 1998-1999, T. H. Tietenberg and H. Folmer, eds., Edward Elgar Publishers, Cheltenham, 89-118.

Gawel, E. (1991). *Umweltpolitik durch gemischten Instrumenteneinsatz: allokative Effekte instrumentell diversifizierter Lenkungsstrategien für Umweltgüter*, Duncker und Humblot, Berlin.

Gawel, E. (1993). "Vollzugsunterstützung regulativer Umweltpolitik durch ergänzende Anreizsysteme." *Zeitschrift für Umweltpolitik und -recht*, 16, 461-475.

Gersbach, H. (2002). "How to get firms to invest: a simple solution to the hold-up problem in regulation." *Review of Economic Design*, 7, 45-56.

Gersbach, H., and Requate, T. (2004). "Emission taxes and optimal refunding schemes." *Journal of Public Economics*, 88, 713-725.

Grubb, M., Chapius, T., and Ha Doung, M. (1995). "The Economics of Changing Course: Implications of Adaptability and Inertia for Optimal Climate Policy." *Energy Policy*, 23, 417-432.

Grubb, M., and Ulph, D. (2002). "Energy, Environment, and Innovation." *Oxford Review of Economic Policy*, 18, 92-106.

Gunningham, N., and Grabosky, P. (1998). *Smart regulation: designing environmental policy*, Clarendon Press/Oxford University Press, Oxford/New York.

Hansjürgens, B., and Fromm, O. (1996). "Emission trading in theory and practice. An analysis of RECLAIM in Southern California." *Environment and Planning C: Government and Policy*, 14, 367-384.

Harrington, W. (1988). "Enforcement leverage when penalties are restricted." *Journal of Public Economics*, 37, 29-53.

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

Howarth, R. B., Haddad, B. M., and Paton, B. (2000). "The Economics of Energy Efficiency: Insights from Voluntary Participation Programs." *Energy Policy*, 28, 477-486.

Innes, R. (1996). "Regulating Automobile Pollution under Certainty, Competition, and Imperfect Information." *Journal of Environmental Economics and Management*, 31, 219-239.

Jacoby, H. D., and Ellerman, A. D. (2004). "The Safety Valve and Climate Policy." *Energy Policy*, 32, 481-491.

Jaffe, A. B., Newell, R. G., and Stavins, R. (2005). "A Tale of Two Market Failures: Technology and Environmental Policy." *Ecological Economics*, 54, 164-174.

Jaffe, A. B., Newell, R. G., and Stavins, R. N. (2002). "Environmental Policy and Technological Change." *Environmental and Resource Economics*, 22, 41-69.

Johnstone, N. (2003). "The Use of Tradable Permits in Combination with Other Policy Instruments." ENV/EPOC/WPNEP/(2002)28, Organisation for Economic Cooperation and Development (OECD), Paris.

Jung, C., Krutilla, K., and Boyd, R. R. (1996). "Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives." *Journal of Environmental Economics and Management*, 30, 95-111.

Katsoulacos, Y., Ulph, A., and Ulph, D. (2001). "The Effects of Environmental Policy on the Performance of Environmental Research Joint Ventures." Behavioral and Distributional Effects of Environmental Policy, C. Carraro and G. E. Metcalf, eds., University of Chicago Press, Chicago, 309-339.

Katsoulacos, Y., and Xepapadeas, A. P. (1996). "Environmental Innovation, Spillovers and Optimal Policy Rules." Environmental Policy and Market Structure, C. Carraro, Y. Katsoulacos, and A. P. Xepapadeas, eds., Kluwer Academic Publishers, Dordrecht, 143-150.

Keck, O. (1987). "Private Information as a Cause of Transaction Failure in Markets, Regulation, Hierarchy, and Politics." *Journal of Conflict Resolution*, 31, 139-163.

Knorring, E. v., and Welzel, P. (1998). "Effiziente Umweltauflagen durch abgabenorientierte Sanktionierung?" *Zeitschrift für Umweltpolitik und -recht*, 21, 341-358.

Kohn, R. E. (1991). "Porter's combination tax and subsidy or controlling pollution." *Journal of Environmental Systems*, 20, 179-188.

Kolstad, C. D. (1987). "Uniformity versus Differentiation in Regulating Externalities." *Journal of Environmental Economics and Management*, 14, 386-399.

Kopp, R. J., Morgenstern, R. D., and Pizer, W. A. (1997). "Something for everyone: a climate policy that both environmentalist and industry can live with." *Weathervane Feature*, Resources for the Future, Washington, DC.

Kopp, R. J., Morgenstern, R. D., Pizer, W. A., and Toman, M. A. (1999). "A Proposal for Credible Early Action in U.S. Climate Policy." *Weathervane Feature*, Resources for the Future (RFF), Washington, D.C.

Krupnick, A. J., Oates, W. E., and 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.

Kwerel, E. (1977). "To tell the truth: imperfect information and optimal pollution control." *Review of Economic Studies*, 44, 595-601.

Magat, W. A. (1978). "Pollution Control and Technological Advance: A Dynamic Model of the Firm." *Journal of Environmental Economics and Management*, 5, 1-25.

McGartland, A. M., and Oates, W. E. (1985). "Marketable Permits for the Prevention of Environmental Deterioration." *Journal of Environmental Economics and Management*, 12, 207-228.

McKibbin, W. J., and Wilcoxen, P. (1997a). "A Better Way to Slow Global Climate Change." *Brookings Policy Brief* 17, Brookings Institution, Washington, DC.

McKibbin, W. J., and Wilcoxen, P. (1997b). "Salvaging the Kyoto Climate Change Negotiations." *Brookings Policy Brief* 27, Brookings Institution, Washington, DC.

Milliman, S. R., and Prince, R. (1989). "Firm Incentives to Promote Technological Change in Pollution Control." *Journal of Environmental Economics and Management*, 17, 247-265.

Montgomery, W. E. (1972). "Markets in Licenses and Efficient Pollution Control Programs." *Journal of Economic Theory*, 5, 395-418.

Newell, R. G., and Pizer, W. A. (2003). "Regulating stock externalities under uncertainty." *Journal of Environmental Economics and Management*, 45, 416-432.

OECD. (2007). *Instrument Mixes for Environmental Policy*, Organisation for Economic Cooperation and Development (OECD), Paris.

Palmer, K., Sigman, H., and Walls, M. (1997). "The Cost of Reducing Municipal Solid Waste." *Journal of Environmental Economics and Management*, 33, 128-150.

Palmer, K., and Walls, M. (1997). "Optimal policies for solid waste disposal: taxes, subsidies, and standards." *Journal of Public Economics*, 65, 193-205.

Petrakis, E., Sartzetakis, E. S., and Xepapadeas, A. P. (2005). "Environmental Information Provision as a Public Policy Instrument." *Contributions to Economic Analysis & Policy*, 4, Article 14.

Pigou, A. C. (1920). *The Economics of Welfare*, Macmillan, London.

Pizer, W. A. (1999). "The optimal choice of climate change policy in the presence of uncertainty." *Resource and Energy Economics*, 21, 255-287.

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

Porter, R. C. (1974). "The long-run asymmetry of subsidies and taxes as antipollution policies." *Water Resources Research*, 10, 415-417.

Portney, P. R. (2000). "Air Pollution Policy." Public Policies for Environmental Protection, P. R. Portney and R. N. Stavins, eds., RFF Press, Washington, DC, 77-123.

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

Rolfe, C., Haites, E. F., and Hornung, R. (1999). *Policies That Could Complement a Domestic Emissions Trading System for Greenhouse Gases*, Multistakeholder Expert Group on Domestic Emissions Trading, National Round Table on the Environment and the Economy, Ottawa.

Sandmo, A. (1976). "Direct versus Indirect Pigovian Taxation." *European Economic Review*, 7, 337-349.

Schwarze, R. (1995). "Haftungsrecht und Auflagen als Policy-Mix - Ein Überblick." *Jahrbuch für Wirtschaftswissenschaften*, 46, 306-326.

Sigman, H. (1995). "A Comparison of Public Policies for Lead Recycling." *RAND Journal of Economics*, 26, 452-478.

Sijm, J. (2005). "The interaction between the EU emission trading scheme and national energy policy schemes." *Climate Policy*, 5, 79-96.

Smith, S. (1999). "The Compatibility of Tradable Permits with Other Environmental Policy Instruments." Implementing Domestic Tradable Permits for Environmental Protection, Organisation for Economic Co-operation and Development (OECD), ed., Organisation for Economic Co-operation and Development (OECD), Paris.

Sorrell, S., Boemare, C., Betz, R., Haralampopoulos, D., Konidari, P., Mavrakis, D., Pilinis, C., Quirion, P., Sijm, J., Smith, A., Vassos, S., and Walz, R. (2003). "Interaction in EU Climate Policy - Final Report to DG Research under the Framework V project 'Interaction in Climate Policy'." Science and Technology Policy Reseach, University of Sussex (SPRU), Brighton.

Sorrell, S., and Sijm, J. (2003). "Carbon Trading in the Policy Mix." *Oxford Review of Economic Policy*, 19, 420-437.

Sterner, T. (2003). *Policy instruments for environmental and natural resource management*, Resources for the Future Press, Washington, DC.

Sunikka, M. (2003). "Energy Certificate in the Energy Performance of Buildings Directive: Effectiveness of the Application on the Existing Housing Stock in the UK." *Working Paper*, OTB Research Institute for Housing, Urban and Mobility Studies, Delft University of Technology, Delft.

Swierzbinski, J. (1994). "Guilty until Proven Innocent - Regulation with Costly and Limited Enforcement." *Journal of Environmental Economics and Management*, 27, 127-146.

Swift, B. (2000). "Allowance Trading and Potential Hot Spots - Good News from the Acid Rain Program." *Environment Reporter*, 31, 354-359.

Swift, B. (2001). "How Environmental Laws Work: An Analysis of the Utility Sector s Response to Regulation of Nitrogen Oxides and Sulfur Dioxide Under the Clean Air Act." *Tulane Environmental Law Journal*, 14, 309-409.

Swift, B. (2004). "Emissions Trading and Hot Spots: A Review of the Major Programs." *Environment Reporter*, 35, 1-16.

Tietenberg, T. (1995). "Tradable Permits for Pollution Control when Emission Location Matters: What Have We Learned?" *Environmental and Resource Economics*, 5, 95-113.

Walls, M., and Palmer, K. (2001). "Upstream pollution, downstream waste disposal, and the design of comprehensive environmental policies." *Journal of Environmental Economics and Management*, 41, 94-108.

Wätzold, F., and Bültmann, A. (2001). "The implementation of EMAS in Europe: A case of competition between standards for environmental systems." Implementing European Environmental Policy, M. Glachant, ed., Edward Elgar, Cheltenham, 134-177.

Weitzman, M. L. (1974). "Prices vs. quantities." *Review of Economic Studies*, 41, 477-491.

Weitzman, M. L. (1978). "Optimal rewards for economic regulation." *American Economic Review*, 68, 683-691.

Wijkander, H. (1985). "Correcting Externalities through Taxes on Subsidies to Related Goods." *Journal of Public Economics*, 28, 111-125.

Williamson, O. E. (1999). "Public and private bureaucracies: a transaction cost economics perspective." *Journal of Law, Economics and Organization*, 15, 306-342.

Yohe, G. W., and MacAvoy, P. (1987). "A Tax Cum Subsidy Regulatory Alternative for Controlling Pollution." *Economic Letters*, 25, 177-182.

Zerbe, R. O. (1970). "Theoretical Efficiency in Pollution Control." *Western Economic Journal*, 8, 364-376.

Zerbe, R. O. J., and McCurdy, H. E. (1999). "The failure of market failure." *Journal of Policy Analysis and Management*, 18, 558-578.