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E.T. and Innovation – Science Fiction or Reality?

An Assessment of the Impact of Emissions Trading on Innovation

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E.T. and Innovation – Science Fiction or Reality?

An Assessment of the Impact of Emissions Trading on Innovation[1]

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Abstract. This discussion paper reviews the literature on experiences with innovation under the existing emissions trading schemes in the USA. The basic result from this review is that the innovation effects triggered by emissions trading have been limited because a) targets were not constraining in the beginning, especially under the RECLAIM program, and b) developments outside the permit markets have been exploited to an extent that was previously unexpected. The latter finding can, however, also be understood in part as a result of market forces finding creative solutions. A further result is that methodological approaches that measure innovation *behaviour* appear to be at least as important for the understanding of the issue as those looking for actual *observed innovatio*n.

JEL: L5; 03; Q 28; Q 48.

Keywords: Regulation, permit trading, empirical evaluation.

1. Introduction

With the consensus reached between the European Parliament and the Council of Ministers of the European Union in July 2003, it is now certain that the EU member states will implement a CO_2 emissions trading scheme for large stationary sources in energy conversion and energy-intensive industries, beginning in 2005 (European Union 2003; for a comment on the general approach, see Gagelmann/Hansjürgens 2002). It will be the world's largest deployment of this environmental policy instrument so far. Given that climate policy goals are frequently very ambitious - the Intergovernmental Panel on Climate Change (IPCC), for example, suggests reducing industrial nations' greenhouse gas emissions by 80% by 2050 - and that innovations display the potential to reduce the long-term cost of this venture dramatically, an important question is: Is emissions trading conducive to innovation?

There is little consensus about this issue. The major emissions trading system currently in place, the "Acid Rain Program" (ARP) in the USA, seems to have created relatively little "real" innovation: Activities do not go far beyond replacing "dirty" coal with "cleaner" coal with lower sulfur content. On the other hand, there is the widely shared belief that emissions trading, henceforth abbreviated as ET, provides a strong and permanent

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incentive for all participants to continually look for new abatement options. These incentives are created by the fact that additional abatement can be converted into "real money" by reducing the burden of buying permits or even by selling spare permits in a well-established ET system.

This discussion paper investigates the issue of the impact of ET on innovation by structuring the evidence to be found in the literature on the first experiences with ET systems in the US. Two questions will be addressed: First, how can we measure the innovation effects that are triggered by ET? Second, does ET have substantial innovation impacts indeed? To answer these questions, one can either look for empirical evidence on whether substantial innovation effects are to be observed in existing ET systems. Alternatively, one can compare ET with a "yardstick" policy instrument. For such a comparison, the typical yardstick is Command-and-Control (CaC) defining e. g. strict individual technology or emission standards. In contrast to the received literature, which focuses on either of these two alternatives, this discussion paper adopts both perspectives.[2]

There is a substantial body of theoretical work comparing ET with both CaC and eco-taxes – see extensive overviews in Kemp (1997) and Jaffe/Newell/Stavins (2000). Two influential articles by Downing/White (1986) and Milliman/Prince (1989) provided the basis for a series of further articles, such as Malueg (1989), Jung/Krutilla/Boyd (1996), Fischer/Parry/Pizer (1998/2003), Requate/Unold (1998/2003), Keohane (1999), and Schwarze (2001). Many of these articles investigate both the magnitude of the innovation effects *and* the question of whether the innovation effects are socially optimal (dynamically efficient), which is relevant due to the fact that there might be "too much" innovation (see e.g. Fischer/Parry/Pizer 2003:525). Moreover, while the reduction of abatement costs due to innovations may be accompanied by ancillary benefits, such as productivity increases with regard to input factors, there might be a "crowding-out" of R&D activities for other purposes (see Jaffe/Newell/Stavins 2000: 32).

The results of these studies critically depend on the assumptions that are invoked, for example, regarding the innovation "spillovers", fixed costs of technology adoption, and the social benefit function. While all these articles are based on perfect competition in both the allowance and product markets, Montero (2002) investigates "direct" as well as "strategic" effects of investments in R&D for abatement-cost-reducing innovation under Cournot (output) and Bertrand (price) competition on product markets. Using Tirole's (1988: 323-336) framework of "top dog", "lean and hungry look" etc., Montero finds that under Bertrand competition, taxes and ET with auctioned allowances provide higher innovation incentives than ET with grandfathered allowances or CaC. Under Cournot competition, ET with grandfathered allowances provides lower incentives than all other instruments.

The empirical literature appears to be less extensive. Work on experiences with ET and innovation has focused on the comparison between ET and CaC, and covers almost exclusively the US schemes on air pollution: Burtraw (2000), Bader (2000), Swift (2001), Keohane (2002), Bañales-Lopez/Norberg-Bohm (2002), Popp (2003) and Ellerman (2003) investigate or report on the innovation impacts of the ARP; Bader (2000) and EPA (2002) deal with the anti-smog policy in the Los Angeles area, and Kerr/Newell (2003) with the Lead Phasedown Program (LPP) for automotive fuels. A brief description on first experiences under the "NO_x Budget Program" in the Northeastern USA is given by Swift (2001). Further research might be expected from ET covering greenhouse gases in Denmark and the UK.

This paper aims at structuring both the theoretical arguments in favour of or against ET and the empirical evidence on the first experiences that can be found in the literature. After clarifying the notions of emissions trading and innovation in Section 2, it attempts to structure the general claims that are made in the discussion (Section 3). The literature on the various existing ET regimes is analysed in Section 4. Conclusions are drawn in Section 5.

2. The Notions of Emissions Trading and Innovation

Following the definition provided by Sorrell/Skea (1999: 1), "[e]missions trading schemes allow participants to exchange permits to emit pollution so as to reduce the cost of meeting an overall environmental goal." The key is the possibility of trade without explicit intervention of governments: Within an ET regime, emissions are avoided wherever it is cheapest, while saved permits migrate to those emitters who need them most.

There are two principal forms of emissions trading, the cap-and-trade and the baseline-and-credit system. Within a cap-and-trade system, a total emission cap, rather than individual

[2] Comparisons with eco-taxes are only briefly addressed in this paper, since eco-taxes have hardly been used in the US and, hence, empirical studies on this issue are not available.

targets, is set, so that the overall amount of emissions is fixed (see Ellerman/Joskow/Harrison 2003: 4). At the end of a compliance period, all the emissions that each participant caused during this period have to be covered by the respective number of permits.[3] Within a baseline and-credit system, individual emission goals, which are often emission rates or efficiency targets, can be set for each participant. Only the gap between actual emissions and predefined emission targets must be covered, and only reductions versus the predefined targets are converted into credits that are eligible for sale. Credits are subject to administrative approval before they can be sold.

A third type of ET, the averaging system, combines elements of both the cap-and-trade and the baseline-and-credit system. The averaging system resembles the baseline-and-credit scheme, except that no pre-trade approval of credits is required (ibid.). While the first ET systems in the US were baseline-and-credit schemes, almost all of the subsequent ET schemes have been of the cap-and-trade type. Only the LPP is an averaging programme without a fixed overall cap. Finally, one can distinguish between "downstream" and "upstream" trading: In downstream-trading systems, it is the emitter who is obliged to hold permits, in upstream-trading systems, it is the supplier or importer of fuels. Except for the LPP, all ET systems discussed here are downstream trading systems.

The process of innovation *in the broader sense* comprises, according to Schumpeter (1939), several steps: invention (conceptualisation as an idea or prototype), innovation in the narrow sense (first commercial application), and diffusion. Innovation in a broader sense can be product as well as process related, and it can be technical, organisational including managerial, social or institutional – see e. g. Rennings (1998). In the literature on innovation experiences with ET, the focus is usually on technical innovations, sometimes extended to organisational and managerial innovation – see Burtraw (2000) and EPA (2002).

In this paper, I adopt the notion of innovation in the broader sense and I focus on innovations that lower *emission abatement costs.* It includes processes or products so far unknown as well as technically feasible solutions that have not been economically relevant so far but might become economically competitive as a consequence of a certain regulation.

Burtraw (2000), Bader (2000), Swift (2001), EPA (2002) and Ellerman (2003) describe the observed innovations mostly qualitatively; they thus focus on innovation outputs, and they only partially compare these to a situation under CaC.

[3] The terms (tradable) „permits“ and „allowances“ are used synonymously throughout this paper.

Keohane (2002) “measures” innovation incentives by the degree of emitters’ sensitivity to abatement cost variations of different technologies. He postulates that this reaction is stronger under an ET than under a CaC regime. Popp (2003) analyses whether there is a more significant progress in terms of abatement efficiency during periods when ET is in place compared to periods when only CaC is in effect. For this purpose, he investigates patents for scrubbers (emission removal units) and reports on their efficiency from a technology database. He distinguishes between *cost saving* innovation and *abatement efficiency* innovation. Kerr and Newell (2003) measure the propensity of technology adoption of firms with low relative to those with high costs of compliance to test whether the difference is larger under ET than under CaC, as theoretically predicted by Malueg (1989).

3. Principal Theoretical Arguments

3.1 Incentives

ET systems induce incessant incentives for the investment in R&D and/or the adoption of new approaches, because the resulting emission abatements lead to lower emission allowance requirements, whereas abatements efforts beyond the level that is required by the legal standard are not remunerated within a CaC regime (see e.g. Tietenberg 1985: 32f., Downing/White 1986, Sorrell/Skea 1999: 12f. and Kerr/Newell 2003). In short, under an ER regime there is a permanent incentive for additional improvements of current technologies. It is important to note that in ET improvements are valuable not only when they lead to cost reductions for a given abatement level (which is valuable also under CaC), but also when they lead to better abatement performance (which is not “rewarded” under CaC, Popp 2003).[4]

Malueg (1989) criticises Tietenberg and Downing/White for making the comparison not comprehensive enough since they only address the emitters with low abatement costs, who would have allowances to sell under E.T. He shows graphically that for emitters with high abatement costs, the adoption incentive would, in contrast, be higher under CaC where they *have to* adopt the new technology to be in compliance while under E.T. they can buy an allowance cheaper than the adoption of the new technology would be. The overall incentive for low cost and high cost firms together, then, is unclear.

[4] As a further argument, it can be stated that under ET, an actor does not have to fear individual “ratcheting“ (tightening of requirements after an innovation has become known). He can therefore be sure to “harvest“ his innovative activity. If at all, ratcheting would be made rather long-term and for the total cap, i.e., affecting all actors. If the innovator remains a seller after ratcheting and subsequent company mitigation activities, the ratcheting can be even be regarded beneficial to him as it keeps allowance prices high.

In this context, it is important to note that in "real life" regulation (e.g., in the USA), CaC requirements for the high-cost emitters are frequently relaxed temporarily or permanently, while they are not accordingly intensified for low-cost emitters (Ellerman 2003: 22.). Then the overall requirements for low cost and high cost firms together are more lenient than formally prescribed – and thus in effect more lenient than an ET system with formally equal targets. This occurs because of information asymmetries between regulators and firms about their true abatement costs: some high-cost emitters identify themselves and ask for relaxation on "unique hardship" grounds, while those firms whose costs are well below average do not identify themselves (ibid.). Under ET, it is much harder for a high-cost emitter to argue for relaxation on unique hardship grounds, when the worst consequence of non-approval of their appeal is that they must buy permits. Furthermore, the transaction costs of such an appeal are often higher than using the permit market for purchases, while they may be lower than the gains from target relaxation under CaC (ibid.).

3.2 Permit Price Trends

The incentive to search for additional abatement is diminished by the persistence of falling permit prices. These may be the consequence of reinforced technological progress due to fostered innovation incentives within an ET system: Permit prices will decrease as long as the regulator does not correctly adjust the overall number of available permits when overall emissions are substantially and constantly decreasing as a consequence of a fostered technological progress that outweighs the environmental impacts of economic growth. In this way, the innovation impacts of ET systems destroy their own basis for further innovation steps (see Milliman/Prince 1989 and the literature following their article). Thus, in Malueg's framework mentioned above, the falling permit prices reduce the additional innovation incentives for low-cost firms and also increase the relative gains for a high-cost firms in using the – now cheaper – permit market rather than adopting the new technology. This does not necessarily mean that the overall incentives are lower under ET – the sizes of the incentives when compared to each other are still ambiguous - but in changes the sizes in favour of CaC.

When innovation occurs, it lowers the overall abatement costs to society. Therefore, a higher abatement level would be optimal and the targets of CaC as well as ET would have to be tightened. However, until such an adjustment is made, ET has the above-mentioned disadvantage of falling allowance prices. A regulator can, of course, set an increasingly stringent target path in advance. His ability to do so, nevertheless, depends on his ability to anticipate technological progress, or to set discretionary target modifications very quickly and reliably (Keohane 1999). Based on arguments drawn from public choice theory and real world political experiences, there are reasons to question the regulator's ability to do this.

Since the empirical literature focuses on the comparison ET vs. CaC, the comparison with eco-taxes in this paper is concentrated on that issue that has the highest prominence in the theoretical literature, namely the price trend. In contrast to allowance prices, the rates of an eco-tax stay the same after innovation occurs, so eco-taxes create a higher abatement incentive than ET as long as the rate of technical progress exceeds the rate of economic growth (and the cap under ET is not reduced accordingly). But is this higher incentive optimal? The answer is no, when following the notion that innovation is not cost-free: The now lower social abatement costs mean that more abatement than before would be optimal, but not to the extent motivated by the – unchanged – tax rate. This holds as long as the marginal social benefit function is falling with increasing abatement efforts, because then at the new optimum the marginal benefits of additional abatements would be lower than those indicated by the tax rate. Conversely, the unchanged cap under ET creates too little incentive, since after innovation, the marginal social abatement costs are lower than the marginal environmental benefits of additional action. When innovation occurs and the regulator can only make discretionary target adjustments with a time-lag, the optimal innovation lies in between the levels induced by ET and eco-taxes, and their relative performance in terms of optimal innovation inducement depends, e.g., on the slope of the marginal benefit function of abatement (Fischer/Parry/Pizer 2003: 534) or the amount of fixed costs (Requate/Unold 2003: 139). On the other hand, the more positive externalities of innovations are assumed which would outweigh their social costs, the higher the likelihood that taxes are more dynamically efficient than ET from a an incentive-based perspective under falling allowance prices.

3.3 Variety of Choices

Apart from the incentive question, to which sections 3.1. and 3.2 refer, the variety of potential compliance options – and therefore also of potential innovative solutions - is a second key prerequisite to harvest market forces in order to achieve the greatest possible dynamic efficiency. According to Swift (2001: 322), every cap-and-trade scheme involves a broader range of available compliance options than all regularly applied forms of CaC: technology standards prescribe certain technological solutions; input-rate standards leave more flexibility than the former but still do not reward efficiency measures that lead to fuel input savings; output-rate standards, finally, do not reward measures of reducing production, such as demand-side management. Under a cap, in contrast, all these measures are viable options.

Moreover, under all forms of ET, the range of compliance options includes – in contrast to CaC – the possibility of "half-way abatement", that is, to reduce emissions only partly and to purchase permits in order to achieve a given reduction target (Bader 2000: 116; Swift 2001). Finally, there is also the business-as-usual option, that is, to buy permits and defer investments in order to implement a much more advanced and possibly less expensive abatement technology later on.[5] The increase in the range of options is accompanied by an increase in competition among alternatives (Burtraw 1996: 80).

3.4 Long-term planning security

While emission targets must be adapted every now and then in order to retain the innovation incentive, the long term planning security for both emitters and suppliers may be reduced. Moreover, radical innovations might be better promoted by granting certain revenues over a limited, but well-defined, time scale rather than immediately exposing them to the competition with other technologies. In the context of renewable energy sources, this argument is a key reason why Denmark, Germany and Spain chose fixed tariff payments instead of quota systems to promote renewables (see Hemmelskamp 1999). Such an approach is particularly appropriate in case of increasing returns (see Arthur 1989): Economies of scale, learning effects, network externalities etc. may lead to short run advantages of incumbent technologies, even if, in the long-run, they should prove to be inferior to technologies that are based on radical innovations.

3.5 "Signalling effects"

ET necessitates that emitters quantify and compile their total relevant emissions. As a consequence, emitters might become aware of the magnitude of their emissions for the first time at all, which may, in turn, lead to the consideration of abatement options and, for instance, to new internal collaboration networks of, e.g., technical and financial personnel.

4. Lessons from the US Emissions Trading Schemes

So far, qualitative as well as quantitative empirical assessments of emissions trading have focused on US experience, in particular on the Acid Rain Program - for descriptions, see for

[5] A further advantage of ET is that it may "mitigate the cost of mistakes" (Ellerman 2000: 191). Finally, safety margins, which are theoretically required under a CaC regime, are obsolete within ET systems, as shortfalls can always be made up by allowances purchases, reducing, for example, redundancy in scrubbers (Swift 2001: 333).

example Fromm/Hansjürgens (1998) and Ellerman et al. (2000). In this section, we deal with the innovation aspects related to these ET systems.

4.1 Acid Rain Program

The most comprehensive reviews on the Acid Rain Program (ARP) have been offered by Burtraw (2000) and Swift (2001). These descriptive analyses arguably include the majority of innovation developments triggered by the ARP. Both authors identify the substitution of *low* for high-*sulfur* coal to be the dominant abatement strategy during the ARP's first phase (1995-2000), followed by end-of-pipe abatement in the form of "scrubbers" that remove SO_2 from the exhausts. The coal switches, though, are, to a great part, due to external price reductions for *low sulfur* coal, which coincided with the introduction of the ARP. In addition, Burtraw (2000: 20) indicates that new approaches, such as "blending" (mixing) of different coal types, occurred in the regulated industries and that the ARP appears to have improved the efficiency in end-of-pipe abatement. Finally, Burtraw (2000: 22) points out innovative re-organisation activities within companies. Bader (2000) and Ellerman (2003) also report these developments, though somewhat less detailed since their focus is more on recent ARP developments in general.

Swift (2001) furthermore finds that especially the advantages of setting caps rather than (technology or rate-based) standards and the fact that "any emission reduction is valuable" (ibid.: 339), have lead to redundancy reducing innovations in scrubbers and their components (ibid.: 333f.), which resulted in lower compliance costs.

Ellerman (2003) points to the fact that the blending experiments were done step by step – not least because even with a small portion of low-sulfur coal, marketable emission reductions could be achieved, while operating safety could be maintained, and subsequently the low-sulfur portion could be continually increased. Also, the "sulfur gradient" (the price "surcharge" for coals with a low sulfur content) resulting from the full flexibility in coal use under ET has lead to increasing efforts to exploit low and mid sulfur coals by producers in the Midwest and the Northern Appalachia region (ibid.).

Both Swift (2001: 333) and Ellerman (2003) report increased utilisation of those power plants that have scrubbers. While this may be considered purely an organisational change, it would be worthwhile to look closer and see whether there are not any new organisational approaches involved.

Popp (2003) analyses scrubber patents and combines this with data on the removal efficiency of installed scrubbers obtained from a plant database by the US Department of Energy (DOE 1999). He finds that although the number of scrubber related patents was lower after 1990 (i.e., when the ARP had been politically decided upon) than before this date, the nature of patented progress changed to be more environmentally friendly: Before 1990 innovations primarily led to cost reductions, whereas after 1990 increases in scrubber performance also could be seen. This could be explained by the fact that abatement costs are, in principle, influenced both by costs <u>and</u> performance, but only under economic instruments can extra abatements be exploited commercially.[6]

Keohane (2002) conducts an empirical comparison of emissions trading and CaC by developing a testable model based on the reasoning that under ET, abatement technique choices should be more sensitive to variation in abatement costs of different abatement options (which is in contrast to Popp's claims, who states that they are equal). After showing this theoretically, he finds quantitative empirical support for his hypothesis by looking at the adoption rate for scrubbers as a response to changes in scrubber prices relative to prices for low-sulfur coals. By using a probit model of 248 firms subject to the ARP and 167 firms under the "New Source Performance Standards" (CaC), he finds that under ET the firms of his sample have indeed responded more strongly to relative cost variations than under CaC.

Overall, under ARP, prices came out to be far lower than previously expected. As a result of discount rates being applied to investments, it appears likely that the prices will increase throughout Phase II, which started in 2000 with more firms and stricter goals. However, this increase will be lower than the intensified goals would indicate, since banking is allowed without restrictions. There seems to be some scope for new technology investment particularly in later years when much of the accumulated banks has been used up.

A further approach to analyse the innovation outcome of ET is to look at which technologies could have been expected to be implemented, but did not diffuse in fact. Here, a deeper literature review would be necessary, which goes beyond the scope of this paper.

[6] Taylor et al. (2003) investigate the innovation related role of regulation in general (instead of an instrument comparison), and in doing so also plot scrubber efficiency before and after 1990 (through 1997), also with data from the Department of Energy (1999) database. In spite of using the same (general) data source as Popp, they find, in contrast to him, no significant increase in scrubber efficiency after 1990. A deeper look at the reason for this difference appears to be necessary.

However, one deeper investigation by Bañales-López/Norberg-Bohm (2002) can be cited which finds that the use of fluidised bed technology by utilities covered by the ARP's Phase I was low in spite of demonstration projects and special provisions for "clean coal technologies" under ARP. Other abatement options were simply cheaper (ibid.: 1179). Another reason proposed is the reluctance to undertake major capital investments in an industry undergoing restructuring (ibid.: 1179).

4.2 RECLAIM

The "Regional Clean Air Incentives Market" (RECLAIM) has been in operation since 1994. The central assessment to date was done by the (federal) US Environmental Protection Agency (EPA) in 2002. It was based on interviews with representatives from companies, administration and other stakeholders (e.g. environmental NGOs). The EPA notes that in the years until 1999, most companies had an excess number of allowances because of a very generous initial allocation (ibid.: 23). This was done to win support for the instrument. It is not surprising that this did not foster many capital expenditures or innovative activities. In fact, EPA (2002: 27) reports that "the market and structure of RECLAIM have not encouraged innovation to the extent anticipated when the program was developed." Furthermore, most industries have relied upon existing "off-the shelf" technologies (ibid.: 26). One of the potential reasons is that some participants missed regulatory certainty (ibid.: 27).

Bader (2000: 114ff) analogously does not find much innovation evidence so far, but reports that some firms searched for and implemented non-technical abatement measures which could be realised because the remainder could be bought on the allowance market – hence the range of compliance options seems to have been enhanced under ET.

A dramatic price spike occurred in 2000 (EPA 2002: 13 ff.): While a "crossover point" where "aggregate actual emissions would approach or potentially exceed total allocations" (ibid.: 13) was already expected for 1998 or 1999, it was instead in 2000 that allowance prices rose, but then to ten times their previous values. An important factor was the Californian electricity crisis, in which power plants which previously had been (partly) unused came to full operation and exhibited a sharp rise in allowance demand. The government had to intervene and sell additional allowances at a fixed price. Over the coming years, the emission targets will be gradually tightened. Since - in contrast to ARP - no banking is allowed under RECLAIM, allowance prices should rise in the future, probably inducing more innovation.

4.3 NO_x Budget Program

In 1999, 12 states in the „Ozone Transport Commission“ (OTC) in the Northeastern USA started a cap-and-trade scheme to combat NO_x as a precursor for ozone leading to summer smog. The first phase required emission reductions of 55-65% compared to 1990 levels. Swift (2001: 372f.) briefly describes first experiences regarding technology choice: In contrast to early expectations that many sources would need to install expensive end-of-pipe technologies such as Selective Catalytic Reduction (SCR, capable of emission reductions of 70-90%), the great majority of the coal-fired units opted for operational changes without significant capital expenses. Through this, they achieved up to 30% emission reductions. Clearly, this was made possible partly by the fact that (some) other installations that *did* implement SCR or other capital intensive technology made up for the difference, and partly by the “half-way” emission reductions themselves. It would need further investigation to determine whether elements of these changes can be termed innovative.

Swift also points to the range of technological options (including capital intensive ones) that are allowed by ET and which have been used, leading to substantial allowance price decreases over time. He also notes very different reduction levels at different units, pointing to different technology use at different points in time at the various installations. Thus, a company that finds it hard to achieve a certain reduction level at one point in time may find it considerably easier a little later.

It seems difficult from this picture to determine exactly how much innovative activity has been motivated, but it is much easier to identify a range of compliance options that were used – driven by the market incentives for *any* emission reductions - and that lead to substantial cost reductions.

4.4 Lead Phasedown Program

Under the nation-wide Lead Phasedown Program (LPP), between 1983 and 1987 a trading provision was incorporated. Kerr/Newell (2003) tested the innovation effects by means of a duration model.[7] Following Malueg’s argument mentioned above, their hypothesis was that the “relative adoption propensity of refineries with low versus high compliance costs was significantly greater under the tradable permit regime than under a nontradable performance standard.” (ibid.: 4). They were able to support this hypothesis by comparing the adoption data for a technology used in the process of lead substitution (isomerisation, ibid.:

13) for those time periods in which ET was applied (1983-1987) to those periods in which performance standards had to be fulfilled by each refinery individually (ibid.: 5f.)[8]. The panel was composed of 378 refineries (ibid.: 12).

Kerr/Newell thus found that innovation effects of ET "provided incentives for more efficient technology adoption decisions" (ibid.: 4). This can be understood as transferring the static (allocation) efficiency argument for economic instruments to the dynamic dimension: the incentives for technology adoption to occur where it is least expensive are greater under ET than under CaC (personal information Newell 19.08.03). This allocation-related dynamic efficiency appears to be different from the question of the efficient (overall) *rate* of innovation as mentioned in Sections 1 and 3. Kerr/Newell also found that adoption of isomerisation was greater in larger refineries (due to economies of scale, management quality, etc., ibid.: 20), but, interestingly, negatively correlated to the overall company size, which they attribute to better access in larger companies to other technologies that help in lead reduction (ibid.: 20).

5. Conclusions

In general, all of the existing US cap-and-trade schemes can be said to have fulfilled the emission goals and brought about substantial cost reductions. This was not least thanks to the fact that the permit markets themselves and the compliance provisions functioned, as a rule, well. Regarding innovation, the picture is not as clear.

In the ARP, prices dropped far more than expected, and this reduced the need for "real" technological advances, e.g. in combustion technologies. Nevertheless, the exploitation of the cost decreases in coal extraction and transportation (and the possible enhancement of these, triggered by ET developments, which Burtraw mentions) can be seen as an innovation of its own - a result of the incentive to "look where others haven't looked before". For the US economy, this exploitation surely has reduced costs as an outcome of employing market forces. Furthermore, there were also „real" innovations, such as in blending, scrubber technology, or organisational changes.

[7] Such a model regards the time until a new technology is adopted by individual actors (see Jaffe/Newell/Stavins 2000: footnote 20 on page 19).

[8] More precisely, Kerr/Newell use ET as an example for an „economic instrument", which they compare with CaC type regulation. In their sample for periods of economic instruments in lead phasedown policy, next to the period with ET they also include a pre-1979 phase of performance standard which allowed flexibility in lead content to the refineries, since they treat this flexibility as qualifying for an „economic instrument" as well.

When arguing that emissions trading lowers the overall technology forcing effect, it must be noted that the flexibility and cost reductions promised by ET "ended a decade-long stalemate on acid rain legislation" (Ellerman/Joskow/Harrison 2003: 34) and won the government the necessary support for stricter goals. Similar effects are reported for RECLAIM and the NO_x Budget Program (ibid.).[9]

For the NO_x Budget Program, similar general statements can be given as for the ARP, except that the developments that brought about the allowance price decreases seem to have involved a greater number of innovative elements than under ARP. A closer look, taking the greater database now existing into account, seems worthwhile. The same goes for the RECLAIM program, where there was little innovation so far, but in recent and coming years targets are substantially tighter and no banked allowances can be used. Especially the experiences with RECLAIM also indicate that the concrete institutional design of ET (such as regulatory certainty or monitoring and enforcement) plays an important role. Experiences with earlier ET systems (i.e., before ARP and RECLAIM) furthermore indicate that allowances should be fully fungible and no public case-by-case approval of each single trade must be required. Only then can market liquidity emerge (Fromm/Hansjürgens 1998: 161), which is likely to be a further important factor for innovation under emissions trading (and less of an issue under other economic instruments such as eco-taxes).

While the question on the *rate* of innovation seems thus hard to answer, the claim that ET leads to a very efficient use of technological or organisational progress appears to be clearly justified. Apart from the several different activities applied, e.g. under NO_x Budget, and the resulting allowance price drops, this is supported by Kerr/Newell's findings on where adoption took place under the Lead Phasedown Program.

When comparing ET with eco-taxes, the author concludes that the relatively lenient targets applied in existing ET programs can be assumed to be temporary, to win support regarding the uncertainties on the emitters' side about this new instrument. In the long-term, targets can be expected to be at least as strict, and probably stricter, than under eco-taxes (with higher innovation incentives as a result), for two political reasons. First, ET allows free allocation of allowances, thus the financial burden on the emitters is far larger under eco-taxes, which should result in more resistance and softer targets. Second, it is suggested that

[9] Of course, the German experience with sulfur abatement in large plants can be seen as a strong counterexample of this plausible argument: substantial cost reductions and innovations were achieved over the years under a CaC policy, which moreover involved far stricter goals than the ARP: -90% instead of -50%.

arguing against a "too high" tax rate is easier than arguing against an overall emissions cap under ET, since the latter can be derived directly from recommendations by scientists.

Regarding empirical investigation methodology, it appears that because of the non-constraining targets (in the first years of RECLAIM) and the developments outside the permit markets which have led to unexpected price drops (in ARP), in the current situation those articles that measure participants' adoption *behaviour* by theoretically derived metrics – like Keohane and Kerr/Newell - appear to have been at least as important for supporting ET's role in innovation inducement as those looking for actual *observed innovation*. Another argument for using such "input" indicators is that the target stringency, a central innovation driver (see Taylor et al. 2003), has been typically different under ET from the stringency under CaC regulations. Thus, quantitative innovation output results could be biased unless corrections are made. Other disturbing factors include science or technology-supply driven factors as well as the ongoing liberalisation in the US electricity industry, which partly coincides with the introduction of ET.

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