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The Design of Permit Schemes and Environmental Innovation

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Abstract

Most real world emission permit schemes are in effect hybrid instruments that feature both quantity and price controls. While the effects of price bounds are well understood for issues such as uncertain abatement costs it has not been investigated how such bounds affect time-consistency of environmental regulation and research incentives. The present paper analyzes these issues for two types of innovation. While price bounds increase static efficiency they reduce incentives to innovate. Commitment on details of a scheme's design might be necessary to avoid the latter.

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Keywords: Environmental Regulation, Hybrid Instruments, Innovation, Time-inconsistency

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1 Introduction

The choice of the regulatory instrument to implement environmental objectives has substantial effects on both static as well as dynamic efficiency.[1] Recent studies on instrument choice in the context of innovation and diffusion of new technologies have focused on prices versus quantities and the time-inconsistency of environmental regulation.[2] A common feature in these papers is to consider time-inconsistency with respect to the stringency of a specific instrument while taking the instrument itself as given. Although it might be reasonably argued that governments manage to commit on quantity regulation by effectively demonizing taxes (as is the case in the US), a permit scheme can easily be designed in a way to mimic a tax. Hybrid instruments as introduced by Roberts and Spence (1976) can be sold as a permit scheme to both industry and the public but effectively impose a regime of price regulation.

A large number of past, current and proposed permit schemes are in fact a combination of quantity and price regulation. Price bounds are rarely called by their real name (however, they have been proposed to be included in what might become the future US climate policy (The-Economist 2007)) but come in a variety of disguises. Fixed penalties for excessive emissions as in the former Danish carbon and the US ODS (ozone depleting substances) programs (OECD 2003) and - the widely used - buyout option in the UK renewables obligation program (DTI 2004) impose an upper bound on the permit price. The same holds for the possibility to earn credits for abatement elsewhere, e.g. using CDM in the European Union Carbon Trading Scheme or in other industries as in the proposed US American Carbon Safety Act (The-Economist 2007), or just by borrowing permits from future periods.

Permit schemes can be - and often are - designed as a hybrid instrument that at least poten-

[1]For a general survey see Cropper and Oates (1992). Jaffe et al. (2002) and Requate (2005a) concentrate on dynamic aspects.

[2]See Laffont and Tirole (1996), Denicolò (1999), Requate and Unold (2003), Requate (2005b), Perino (2008) and Krysiak (2008).

tially mimics a tax. The usual distinction between instrument choice and stringency is, hence, not always appropriate. The penalty for excessive emissions or other details of instrument's design seem not more or less prone to adjustments by the government than the number of permits in the market. While the effects of hybrid instruments is well understood in static contexts this does not hold for the development and diffusion of new technologies. Here, an upper bound on the permit price is likely to affect the economic performance of tradeable permits since new technologies are usually protected by patents that give rise to monopoly pricing. Distortions due to market power in the eco-industry that provides advanced abatement technologies have recently been studied by David and Sinclair-Desgagne (2005), Requate (2005b) and Perino (2008).

The present paper contributes by analyzing the effect of an endogenous design of permit schemes on diffusion of new technologies and innovation incentives. For two types of innovation plain permits, i.e. a scheme without price bounds, are compared to a flexible version where the government can set an upper limit on the permit price.

The main results are that increased flexibility allows to mend static inefficiencies caused by the eco-industry's market power but thereby reduce incentives to innovate. While the former effect is unambiguously positive the latter can be detrimental. Avoiding undesirable reductions in R&D incentives requires commitment on design issues that might be hard to achieve in practice.

2 The Model

Consider two succeeding periods in a competitive market for a non-durable consumption or intermediate good Y. In the first period only one production technology labeled 1 is available. If the eco-industry successfully engages in R&D in the first period, a new technology 2 producing a perfect substitute to Y becomes available in the second period. The market's downward sloping inverse demand function in each period is

$$P = P(Y),$$

where $Y = Y_1 + Y_2$ is the sum of technologies' output.

Individual firms are small, have U-shaped cost functions and entry is free. Both technologies are assumed to exhibit constant returns to scale at the industry level. The industry's cost function is therefore given by

$$C(Y_1, Y_2) = c_1 Y_1 + c_2 Y_2.$$

This cost structure is more general than that of Laffont and Tirole (1996) and Denicolò (1999) by allowing for real economic costs associated with the installation of the new technology (i.e. $c_2 > c_1$).

Technologies might emit pollution as a joint product at a constant ratio to output Y_i. The social damage function D is

$$D(Y_1, Y_2) = D(a_1 Y_1 + a_2 Y_2),$$

where D is increasing and convex and $a_i \geq 0$ for all $i \in \{1, 2\}$ and $a_1 + a_2 > 0$. The latter condition ensures that at least one of the technologies is polluting and the problem therefore relevant for environmental regulation. a_i are exogenous parameters indicating by how much technology 2 is cleaner than technology 1 or vice versa. This specification of the cost and damage functions allows for a number of innovation types. Vertical innovation where the new technology is cleaner, equally costly and hence strictly preferred ($c_1 = c_2, a_1 > a_2$) analyzed by Denicolò (1999) and perfect vertical innovation ($c_1 = c_2, a_2 = 0$) considered by Laffont and Tirole (1996) are special cases of the types used in this paper.[3]

[3]Not all types of innovation consistent with the above specification are considered. Instead the focus is on two exemplary cases that nevertheless extend the set studied by Laffont and Tirole (1996), Denicolò (1999).

The eco-industry invests into R&D according to the expected value of future patents. In case of development of a new technology, the successful research firm is granted a patent in the second period. It is assumed to set a license fee f linear in output of the new technology.[4] Imitation of the new technology is ruled out, hence patents are strong and of sufficient breadth.

The government maximizes social welfare. In the absence of a commitment on either taxes or plain permits, it regulates pollution with a permit quantity E and an upper bound $\overline{\tau}$ on the permit price (Roberts and Spence 1976, Pizer 2002). If the permit price exceeds the threshold, additional permits are sold at this price and the quantity constraint ceases to be binding. This design enables the government to choose endogenously between price and quantity regulation by adjusting stringencies within a given legal framework. The distinction made in the literature between a commitment on instruments and on stringencies becomes obsolete. The situation where the government has full flexibility on all policy variables in the post-innovation period is compared to a commitment on taxes and plain permits.

In what follows, production and emission control in period 1 are ignored as there is nothing new to be learned. In the first period only the research investment matters. If the eco-industry's efforts remain fruitless, nothing changes compared to the first period. However, if research is successful and technology 2 becomes available in period 2 the timing is like in Denicolò (1999), Laffont and Tirole (1996) and Perino (2008). After the new technology has arrived and its properties are known, the government adjusts regulation and grants a patent to the successful research firm. Second, the research firm chooses the level of the license fee f. Third, firms decide to enter or exit the industry, which technology to use and how much to produce.

[4] This is equivalent to a fixed fee per firm as firms are small and face U-shaped cost functions.

3 Vertical Environmental Innovation

Assume that the new technology is equivalent to the established one but emits less of the same pollutant ($0 < a_2 < a_1, c_1 = c_2 = c$, see Figure 1). Hence, the new technology is strictly preferred and innovation is therefore vertical. Without loss of generality assume that $a_1 = 1$. Denicolò (1999) studies this case both with and without commitment on future tax rates and permit quantities but does not consider a price bound. Laffont and Tirole (1996) analyze a limiting case where the new technology is perfectly clean ($a_2 = 0$).

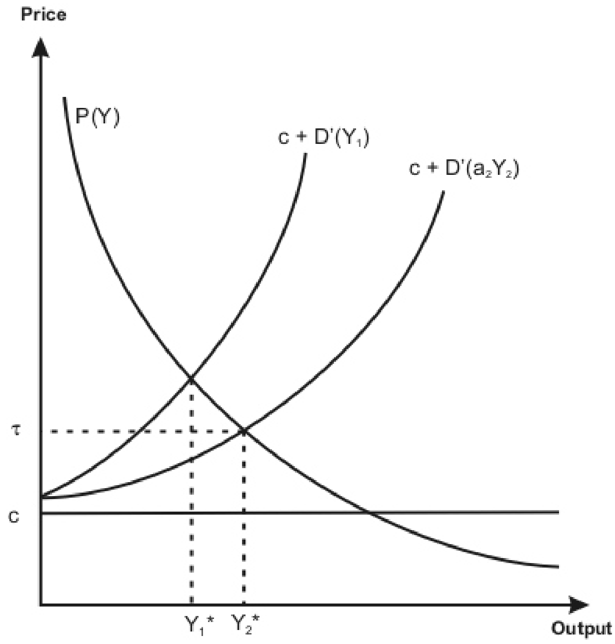

Figure 1: Vertical environmental innovation

3.1 Plain Permits

First, consider the case of plain permits, i.e. without an upper bound on the permit price. The equilibrium conditions in the market clearing stage are given by

$$P(Y) = c + \gamma, \tag{1}$$

$$P(Y) = c + a_2\gamma + f, \tag{2}$$

$$Y_1 + a_2 Y_2 \quad \leq \quad E, \tag{3}$$

where γ is the equilibrium permit price. Firms are indifferent between using the established and the new technology if $f = (1 - a_2)\gamma$. A profit maximizing patent holding firm will ensure that the license fee always satisfies this condition. If $f < (1 - a_2)\gamma$, it could raise the fee without affecting output of the new technology due to the permit constraint or, if $f > (1 - a_2)\gamma$, the new technology is not used at all. Note that this does not yet define the equilibrium license fee. The permit price depends on aggregate output which is itself a function of f implicitly defined by (1)-(3). The patent holder can influence both aggregate output and that of the new technology (Requate 2005b, Perino 2008). Hence, the patent holding firm has some discretion on f while maximizing its profits $\pi = f \cdot Y_2(f)$ subject to the binding permit constraint (3). The first order conditions yield $Y_2 = \frac{E}{a_2}$ and $Y_2 + f\frac{\partial Y_2}{\partial f} = 0$ for $Y_2 < \frac{E}{a_2}$. Substituting in f, (2), Y and $\frac{\partial Y_2}{\partial f} = \left[(1 - a_2)^2 \frac{\partial P}{\partial Y}\right]^{-1}$ yields $Y_2 + \frac{P(E+(1-a_2)Y_2)-c}{(1-a_2)\frac{\partial P}{\partial Y}|_{Y=E+(1-a_2)Y_2}} = 0$ for the case $Y_2 < \frac{E}{a_2}$.

The government aims to implement $Y_2 = \frac{E}{a_2} = Y_2^*$ and $Y_1 = Y_1^* = 0$, where an asterisk denotes static first best levels. However, due to profit maximizing of the patent holding firm this is only possible if

$$-(1 - a_2)^2 \left.\frac{\partial P}{\partial Y}\right|_{Y=Y_2^*} \frac{Y_2^*}{P\left(Y_2^*\right) - c} \leq 1. \tag{4}$$

Otherwise, the patent holder increases the license fee above $f = (1 - a_2)\left[P(Y_2^*) - c\right]$ and thereby reduces output of the new technology below the optimal level and triggers production by the established one. The quantity restriction imposed by permits is not always sufficient to effectively constrain monopoly pricing by the patent holding firm.

Proposition 1 *Monopoly pricing by the patent holding firm creates distortions under plain emission permits if (4) does not hold and innovation is vertical.*

This qualifies a result by Denicolò (1999) who conjectures that permits are efficient by assuming that $Y = \frac{E}{a_2}$.

3.2 Permits with Price Bound

An upper bound $\overline{\tau}$ on the equilibrium permit price can avoid this source of static inefficiency. If $\gamma^e = \min[\gamma, \overline{\tau}]$ is the effective permit price and $\overline{\tau} = P(Y_2^*) - c$, this imposes an upper bound of $(1 - a_2)\,[P(Y_2^*) - c]$ on the license fee. For license fees exceeding this threshold, the permit constraint ceases to be binding and the entire output is produced by the established technology. This is not in the interest of the patent holding firm. Hence, with $\overline{\tau} = P(Y_2^*) - c$ any $E \leq a_2 Y_2^*$ implements the first best static optimum. This includes $E = 0$, i.e. a standard emission tax.

Proposition 2 *Emission permits with an upper price bound and taxes are statically efficient under vertical innovation.*

Note, in all cases where the advanced design increases static efficiency patent holder's profits and hence research incentives are strictly lower under the flexible design than under plain permits. The bound on permit price restricts profit maximizing of the research firm. Plain permits fail to implement the static first best in general, while taxes are equivalent to the flexible scheme. The government is therefore indifferent between a tax and the flexible instrument both ex-ante and ex-post. Whether it prefers plain permits or the flexible scheme/taxes ex-ante depends on the trade-off between static and dynamic efficiency. If taxes induce excessive R&D incentives they clearly dominate plain permits. However, if plain permits result in under-investment in R&D, they might well be preferred ex-ante. In this case the government has incentives to commit on future design of environmental regulation.

Proposition 3 *Research incentives are less under the flexible scheme than with plain permits whenever flexibility is of value ex-post. The flexible design is equivalent to a pollution tax both in static and dynamic terms.*

Research incentives are strictly positive because the externality requires a reduction in output of the new technology compared to a situation without market failures. Thereby firms have a positive willingness to pay for the new technology given static optimal regulation.[5] The patent holding firm can appropriate this amount by license fees. However, unless plain permits are used, monopoly pricing does not distort the allocation. Hence, there is no time-inconsistency with respect to patent law. Granting intellectual property rights is a credible promise. However, the dynamic incentives created are solely determined by the size of the externality of the new technology and therefore only by chance first best.

4 A Polluting Industry Facing a Clean Substitute

In this section a different type of innovation is considered. Contrary to the type in the previous section, the new technology has higher marginal costs than the established one ($c_1 < c_2$) but is perfectly clean ($a_2 = 0$). Assume that the new technology is socially desirable but not strictly superior to the established one (see Figure 2). This case has been studied by Abrego and Perroni (2002) but for adoption decisions instead of R&D. Again, the model by Laffont and Tirole (1996) is a limiting case where the private costs of production of the new technology become arbitrarily close to that of the established technology ($c_1 + \epsilon = c_2$). Electricity production is a case in point where wind and solar power are clean but so far more expensive alternatives to nuclear power and fossil fuels. Similarly, fuel cells provide a clean substitute to traditional combustion engines but currently at higher private costs.

4.1 Plain Permits

The equilibrium of the production stage with plain permits is given by

$$\begin{aligned} P(Y) &= c_1 + \gamma, \\ P(Y) &= c_2 + f, \\ Y_1 &\leq E, \end{aligned}$$

[5] This does not hold if the new technology is perfectly clean, i.e. $a_2 = 0$ (Laffont and Tirole 1996).

where γ is the equilibrium permit price. The above system of equations determines the equilibrium output quantities Y_1 and Y_2 and the equilibrium permit price, i.e. $\gamma = c_2 - c_1 + f$ if both technologies are used at the same time as is socially optimal (see Figure 2).

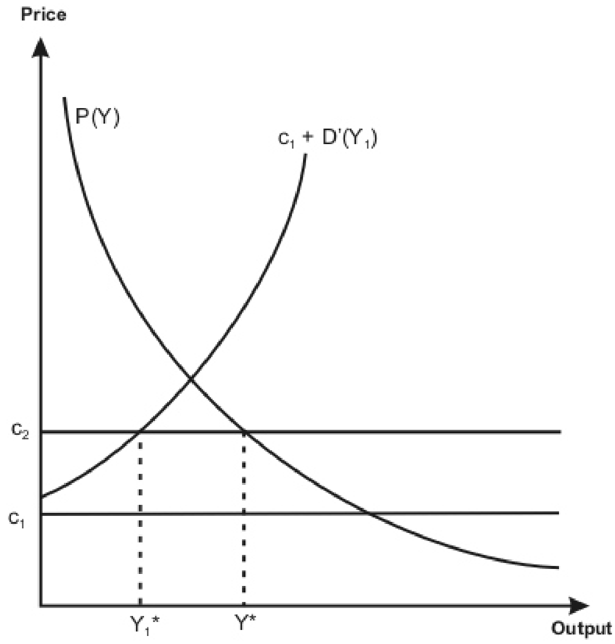

Figure 2: A clean but expensive substitute

In the previous stage the patent holding firm faces a residual demand of

$$\tilde{Y}_2(f) = Y(c_2 + f) - E.$$

The research firm maximizes profits $\pi = f \cdot \tilde{Y}_2(f)$ over f. The equilibrium license fee $\hat{f} > 0$ is defined by the standard monopoly pricing condition $-\frac{\partial Y}{\partial P} \frac{\hat{f}}{\tilde{Y}_2(\hat{f})} = 1$.

The government chooses the permit quantity E to maximize post-innovation welfare. The corresponding first order condition is

$$\frac{\partial W}{\partial E} = \frac{\partial Y}{\partial E} [P(Y(E)) - c_2] - c_1 - D'(E) + c_2 = 0,$$

where $\frac{\partial Y}{\partial E} = \frac{\partial Y}{\partial P} \frac{\partial \hat{f}}{\partial E} > 0$. Since $-c_1 - D'(E) + c_2 = 0$ is the condition for the social optimum and $\frac{\partial Y}{\partial E} [P(Y(E)) - c_2] > 0$, the second-best permit quantity E^{plain} and hence equilibrium output of technology 1 is strictly larger than the social optimum Y_1^*.

Proposition 4 *Monopoly pricing by the patent holding firm creates distortions under plain emission permits if a polluting industry faces a perfectly clean but expensive substitute. Aggregate output is too low while emissions are too high.*

4.2 Permits with Price Bound

In this regulatory setting the equilibrium permit price is bound from above and hence $\gamma = \min[c_2 - c_1 + f, \overline{\tau}]$. The residual demand of the patent holding firm under the flexible scheme is therefore

$$\tilde{Y}_2(f) = \begin{cases} 0 & : \; f > c_1 - c_2 + \overline{\tau} \\ Y(c_2 + f) - E & : \; 0 \leq f < c_1 - c_2 + \overline{\tau}. \end{cases}$$

The equilibrium license fee is $f = \min[\hat{f}, c_1 - c_2 + \overline{\tau} - \epsilon]$, where ϵ is arbitrarily small. The maximum permit price $\overline{\tau}$ thereby indirectly imposes also an upper bound on the license fee.

In the first stage, the government sets the policy variables E and $\overline{\tau}$ to maximize post-innovation static welfare. Use of the new technology is socially optimal which requires $\overline{\tau} > c_2 - c_1$. However, any increase of $\overline{\tau}$ above this threshold results in a rise of f and therefore in a price increase and in an undesirable reduction of aggregate output. The static social optimum is therefore implemented by setting $\overline{\tau} = c_2 - c_1 + \epsilon$ and E such that $D'(E) = c_2 - c_1$. Hence, $f = 0$.

Proposition 5 *Emission permits with an upper price bound are statically efficient but expropriate the patent holding firm if a polluting industry faces a perfectly clean but expensive substitute.*

Market power and research incentives, purposely generated by patent law, are destroyed by an opportunistic use of environmental regulation. In contrast to the type of innovation considered in section 3, static efficiency and positive research incentives can not coincide. Hence, although the government is likely to prefer plain permits ex-ante[6] it has incentives to impose a price bound ex-post. In order to stimulate innovation via patents the government has to credibly commit

[6]This is not the case if the static distortions exceed the social gain of innovation.

both to grant and enforce intellectual property rights and to details of future environmental regulation. While the credibility of patents has received considerable attention, commitment problems arising from the design of environmental regulation have so far been neglected.

Taxes are not able to achieve the static first best in this setting. Due to constant returns to scale either one technology is used exclusively or if firms are indifferent, a random mix of technologies results.

5 Conclusion

Most real world permit schemes incorporate mechanisms that effectively impose an upper bound on the permit price. However, with a hybrid scheme the common distinction between a commitment on the instrument and its stringency is not appropriate. A quantity instrument such as tradeable permits can easily be turned into a price instrument by an adequate adjustment of the upper price bound - a parameter as easily changed as the number of permits available.

The hybrid nature of permit schemes and the potential lack of commitment to design details have important repercussions on the diffusion of new technologies and R&D incentives. While the flexibility gained by the opportunity to directly control the permit price reduces distortions caused by market power of the eco-industry, it diminishes incentives to invest in the development of cleaner technologies.

The negative effects on research incentives can only be avoided by committing on the future design of permit schemes. Something that - though not infeasible - is likely to be harder to achieve than a commitment on the instrument used and that should be taken into account when designing new permit schemes, e.g. to implement any future US climate policy.

References

Abrego, L. and Perroni, C.: 2002, Investment subsidies and time-consistent environmental policy, *Oxford Economic Papers* **54**, 617–635.

Cropper, M. L. and Oates, W. E.: 1992, Environmental economics: A survey, *Journal of Economic Literature* **30**, 675–740.

David, M. and Sinclair-Desgagne, B.: 2005, Environmental regulation and the eco-indurstry, *Journal of Regulatory Economics* **28**(2), 141–155.

Denicolò, V.: 1999, Pollution-reducing innovations under taxes and permits, *Oxford Economic Papers* **51**, 184–199.

DTI: 2004, New and renewable energy - prospects for the 21st century, *The renewables obligation order 2005 statutory consultation*, Department of Trade & Industry, London.

Jaffe, A. B., Newell, R. G. and Stavins, R. N.: 2002, Environmental policy and technological change, *Environmental and Resource Economics* **22**, 41–69.

Krysiak, F. C.: 2008, Prices vs. quantities: The effects on technology choice, *Journal of Public Economics* **forthcoming**, doi:10.1016/j.jpubeco.2007.11.003.

Laffont, J.-J. and Tirole, J.: 1996, Pollution permits and environmental innovation, *Journal of Public Economics* **62**, 127–140.

OECD: 2003, The use of tradable permits in combination with other environmental policy instruments, *Report*, OECD, Paris.

Perino, G. S.: 2008, The merits of new pollutants and how to get them when patents are granted, *Environmental and Resource Economics* **forthcoming**, doi:10.1007/s10640–007–9155–y.

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

Requate, T.: 2005a, Dynamic incentives by environmental policy instruments - a survey, *Ecological Economics* **54**, 175–195.

Requate, T.: 2005b, Timing and commitment of environmental policy, adoption of new technology and repercussions on R&D, *Environmental and Resource Economics* **31**(2), 175–199.

Requate, T. and Unold, W.: 2003, Environmental policy incentives to adopt advanced abatement technology: Will the true ranking please stand up?, *European Economic Review* **47**, 125–146.

Roberts, M. J. and Spence, M.: 1976, Effluent charges and licenses under uncertainty, *Journal of Public Economics* **5**, 193–208.

The-Economist: 2007, Getting the message, at last, *Nov 15th* .