On the Long-Run Efficiency of Auctioned vs. Free Permits

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Abstract

When marketable emission permits affect the entry and exit decisions of competitive firms, all permits should not be distributed free of charge. Depending on the nature of the pollutant, an optimal share of the permits should be auctioned with others freely distributed to ensure long-run efficiency. All of the permits should be auctioned for global pollutants, but for local pollutants, some of the permits should be free.

Theoretical work on the properties of marketable pollution permits has yielded many important practical guidelines for designing such schemes. One such insight is that, in most circumstances, any initial allocation of permits among firms will result in an efficient allocation of emissions after firms exhaust all gains from trade.[1] This is very appealing from a policy perspective as it suggests that in the design of marketable permit systems, the regulatory authority need not be concerned with the pre-trading allocation of permits among sources. However, this result says nothing about whether the initial set of permits should be auctioned or provided free of charge to the initial permit holders.

The most prevalent thinking on this topic seems to be that whether the initial permits are auctioned off to firms, given away free, or some combination of the two, can be decided purely on political grounds, presumably with little or no efficiency losses. This has been specifically mentioned as a beneficial aspect of marketable permits relative to emission taxes (Hanley, Shogren and White (1996), Xepapadeas (1997), and Baumol and Oates (1988)).[2] Unfortunately, there is little theoretical work to support this view, and generally little formal analysis of the efficiency implications of auctioning off the initial distribution of permits relative to free dispersal. Milliman

[1] A notable exception is provided in Hahn (1984) where he demonstrates that the presence of imperfect competition in the permit market destroys this property.

[2] For example, Baumol and Oates (1988) argue that a free initial distribution of permits "effectively eliminates the added costs for existing firms [of emission taxes] without any necessarily adverse consequences for the efficiency properties of the program and with some obvious and major advantages for its political acceptability" (page 179).

and Prince (1989) demonstrate that auctioned permits provide more incentive for individual firms to innovate and adopt new abatement technologies than free permits, and Jung, Krutilla and Boyd (1996) show that this holds true for an industry with a fixed number of firms. But otherwise on pure efficiency grounds, auctioned and free permits are considered to be equivalent.

In this paper, we seek to make a simple but important and apparently overlooked point: auctioned and free permits have different long-run efficiency implications. The long-run problems are akin to those that arise when subsidies to firms that reduce pollution are used as an alternative to emission taxes. As Baumol and Oates (1988) demonstrate, a subsidy per unit of pollution reduction provides firms a lump sum transfer that lowers their average cost of production relative to a tax scheme. Thus, firms that might otherwise exit may stay in business and firms that might otherwise stay away from the industry may enter. Marketable pollution permits provided free of charge to firms are likewise a valuable asset and in most circumstances can have long-run efficiency complications similar to a subsidy.

As Carlton and Loury (1980) have shown, to achieve long-run efficiency in a competitive industry, the regulatory authority needs to control both the pollution level of each firm and the number of firms. It is to be expected then that a single policy tool, such as a Pigouvian tax or the choice of a number of marketable permits, will not generally achieve a first best allocation. However, we show that by appropriately choosing the proportion of free permits in addition to the total number of permits, long-run efficiency *can* be restored. Intuitively, the proportion of permits allocated for free is the second policy tool that is needed to achieve long-run efficiency. Further, we show that the efficient proportion of free permits depends upon the type of pollutant and we identify the specific situations in which (at least some) free permits are efficient and those situations in which all permits should be auctioned.

In a different context, Collinge and Oates (1982) recognized that competitive firms pay too much (compared with the actual damage from pollution) if a Pigouvian tax is imposed, or if all permits are auctioned at the market equilibrium price. They suggested a system of rental emission permits in which firms pay the actual pollution damage. The price of each unit of permit equals the marginal damage caused by that unit of pollution, and thus depends on how many permits a firm has already used. Although theoretically appealing, this system would be daunting to implement in practice.[3]

In contrast, we demonstrate that initial permit allocation mechanisms (in which permits are either auctioned or freely distributed) can be harnessed to achieve long-run efficiency. Our results are relevant for two typical situations concerning permit allocations: one in which a new set of permits are allocated in each period and one in which a set of permits are allocated one time only but the permit policy is anticipated by firms. In the first case, since new permits are issued in each period (say each year), free permits represent an annual "subsidy" to existing firms, clearly affecting the entry and exit decisions of the firms. One example of this case is the five-year lead phase-out program of the 1980's where permits were accrued quarterly. Similarly the California Low Emission Vehicle Program generates tradeable credits annually for automobile manufacturers whose fleet betters the average emission requirement.

It might seem in the second case, when permits are provided to firms one time only and represent permanent endowments to the right to pollute, that the initial allocation is simply a transfer with no further efficiency consequences. After all, future entrants will have to purchase permits from existing firms and those who wish to exit the industry can freely sell their permits. However, if firms rationally expect the government's permit decision in the future and make the corresponding entry and exit decisions now, then the income transfer may affect these decisions. In particular, if a firm

[3]Even though Collinge and Oates (1982) address the same general topic as this paper, it is interesting that their concern stemmed from firms paying "too much" in a Pigouvian tax or auctioned permit system. In contrast, our concern is the potential for excessive entry that free initial permits might induce.

expects that the permits will be given free for the firms existing at the moment of policy change, it may enter the industry before the provision takes place. Given that the policy debate concerning emissions trading is typically protracted, firms likely have ample opportunity to anticipate the government's policy choice. In fact, many times firms themselves take an active role in pushing for specific regulatory policies. For example, currently utility firms are pushing the federal government to allow credits for early action in reducing greenhouse gas abatement following the Kyoto Protocol (Cushman (1999)).

1 A Model of Optimal Permit Allocation

Consider a perfectly competitive industry with identical firms. The aggregate inverse demand function for its output is given by $P(\cdot)$ and the cost function of each firm is given by $c(q,a)$, where q is the firm's output and a is its abatement effort. We make the standard assumptions about the cost function, namely $c_q > 0$, $c_{qq} > 0$, $c_a > 0$, $c_{aa} > 0$, and $c_{qa} > 0$. The emission of an individual firm is given by $e(q,a)$, with $e_q > 0$, $e_{qq} > 0$, $e_a < 0$, and $e_{aa} > 0$. Let n be the number of identical firms in the industry. In the spirit of Carlton and Loury (1980), we let $D(n,e)$ be the environmental damage caused by the emission of the industry. We assume that $D_n \geq 0$, $D_e \geq 0$, and the Hession matrix of D is positive semi-definite.

Let E be the total number of permits issued to the industry and e_0 be the permits given free to each firm with the remaining permits auctioned off at the market price. With free entry, the government chooses E and e_0 to influence both the decisions of each firm (i.e. q and a) and the number of firms.[4] Since there is a one to one correspondence between E and the equilibrium

[4] In our model, entry and exit can be considered as a surrogate for firms' other responses such as increasing or decreasing emissions before the policy. For example, if a firm's initial allocation of free permits depends on its historical average emission level, then anticipating such a policy, the firm has an incentive to increase its emissions now to obtain more permits in the future. This is similar to the "entry" decision modeled in this paper.

price of the permits, denoted as p, we can model p and e_0 as the two policy tools available to the government.

Given p and e_0, each firm's profit is given by $\pi = P(nq)q - c(q,a) - p(e(q,a) - e_0)$, where $e(q,a) - e_0$ is the number of permits the firm must purchase at the market price. The industry equilibrium is characterized by the optimization conditions of the firm,

$$P(nq) - c_q(q,a) - pe_q(q,a) = 0, \tag{1}$$

$$c_a(q,a) + pe_a(q,a) = 0, \tag{2}$$

and the zero profit condition $\pi = 0$. The three conditions fully determine q, a, and n as functions of p and e_0.

If the government is to choose q, a, and n, its optimization problem is $\max_{q,a,n} u(q,a,n) \equiv \int_0^{nq} P(x)dx - nc(q,a) - D(n, e(q,a))$. The first order conditions are given by

$$P(nq) - c_q(q,a) - D_e(n,e)e_q(q,a)/n = 0 \tag{3}$$

$$c_a(q,a) + D_e(n,e)e_a(q,a)/n = 0 \tag{4}$$

$$P(na)q - c(q,a) - D_n(n,e) = 0. \tag{5}$$

Comparing the two set of optimal conditions, we immediately see that the optimal government policy is

$$p^* = \frac{D_e(n, e(q,a))}{n}, \qquad e_0^* = e(q,a) - \frac{nD_n(n, e(q,a))}{D_e(n, e(q,a))}, \tag{6}$$

where q, a, and n are evaluated at their respective optimal levels. The Pigouvian tax that equals the marginal damage caused by an individual firm's emission is p^*. Correspondingly, the total number of permits to be issued to the industry is given by $E^* = n(p^*, e_0^*)e(q(p^*, e_0^*), a(p^*, e_0^*))$.

From (6), we know that the necessary and sufficient condition for $e_0^* = e(q,a)$, i.e. for all the initial permits to be freely allocated, is $D_n = 0$, that is when the total pollution damage depends only on the emission of each firm, but not on the number of firms. The condition for $e_0^* = 0$, i.e. the situation when all permits should be auctioned, is $eD_e = nD_n$, or $\varepsilon_e^D = \varepsilon_n^D$, where $\varepsilon_e^D(n,e) = D_e(n,e)e/D(n,e)$ is the elasticity of pollution damage with respect to each firm's emission, and $\varepsilon_n^D(n,e) = D_n(n,e)n/D(n,e)$ is the elasticity with respect to the number of firms. Thus auctioning all initial permits is efficient only when the pollution damage is equally sensitive to the emission level of each firm and the number of firms.[5] More generally, we know

Proposition 1 *The efficient proportion of free permits is given by*

$$\frac{e_0^*}{e^*} = 1 - \frac{\varepsilon_n^D}{\varepsilon_e^D}. \tag{7}$$

Therefore (a) all permits should be free if and only if $\varepsilon_n^D = 0$, (b) all permits should be auctioned if and only if $\varepsilon_e^D = \varepsilon_n^D$, and (c) part of the permits should be auctioned when $\varepsilon_e^D > \varepsilon_n^D$, that is when the pollution damage is more sensitive to the emission level of each firm than to the number of firms.[6]

To understand the intuition of Proposition 1, note that pe_0 can be considered as an income transfer from the government to the firm. Similar to Carlton and Loury (1980), we can show that a subsidy will reduce a competitive firm's scale q and emission e and raise the number of firms. This is because a competitive firm produces at the point where the average cost equals the marginal cost. A subsidy reduces the average cost, and since marginal cost is increasing in q, it will reduce q. Since a subsidy always raises the total supply of the industry, it will raise the number of firms as each firm's output is reduced. Since the total emission level is fixed at E, each firm's emission $e = E/n$ will decrease. Therefore, if the environmental damage is more sensitive to each firm's

[5] Spulber (1988) showed that an auctioned permit system is efficient for a damage function given by $D(n,e) = \bar{D}(ne)$, that is, when the pollution damage depends on the total emissions only. Since in this special case $\varepsilon_e^D = \varepsilon_n^D$, Spulber's result is consistent with our model.

[6] If $\varepsilon_n^D > \varepsilon_e^D$, $e_0^* < 0$ and each firm should be levied a fixed number of permits. As we will argue in the next section, this scenario is unlikely to arise in the real world.

emission level than to the number of firms, a subsidy is needed to reduce the emission level, even though it raises the number of firms. However, all permits being free may also be inefficient because the number of firms may be too high and the scale of each firm may be too low.

Note that the suggested policy choice achieves first best because the industry equilibrium conditions replicate the government's first order conditions. Essentially in the long run the government needs to control two quantities, e and n. A single Pigouvian tax p, or a single policy of the number of permits E, cannot control the two quantities to their first best levels at the same time. However, with e_0, the government has two instruments to control two quantities, enabling it to restore a first best allocation.

2 Implications of the Pollutant's Damage Function

Proposition 1 indicates that the optimal proportion of free permits depends on the characteristics of the pollution damage function. For uniformly mixed pollutants, only the aggregate emission matters, thus $D(n,e) = \bar{D}(ne)$, and $\varepsilon_e^D = \varepsilon_n^D$. In this case, all permits should be auctioned. Pollution problems falling into this category include global warming, ozone depletion, some regional air pollution such as acid rain, etc.

For purely local pollutants, a firm's emission causes damage only in a restricted area, and the damage function may be represented by $D(n,e) = nd(e)$, where $d(\cdot)$ is the damage caused by a single firm. In this case, $\varepsilon_n^D(n,e) = 1$. If we assume that $d(\cdot)$ is increasing and convex, and $d(0) = 0$, it is easy to show that $\varepsilon_e^D(n,e) > 1$ for all $e > 0$.[7] Therefore, $e_0^* > 0$ and some of the permits should be free. The special damage function requires that each firm's pollution damage be completely independent of other firms' emissions. For example, if the firms are geographically separate such

[7] To see this, note that $\varepsilon_e^D - 1 = (d'(e)e - d(e))/d(e)$. The numerator is increasing in e and equals zero at $e = 0$, thus is positive for $e > 0$. Then $\varepsilon_e^D > 1$ for $e > 0$.

that their emissions do not mix, this damage function would be appropriate.

Some pollutants cause both local and global damages. For example, nitrogen oxides contribute to both global warming and local smog. Then the damage function may be a weighted sum of $\bar{D}(ne)$ and $nd(e)$, and again some, but not all, of the permits should be freely distributed. Another example of a weighted sum damage function is when there are multiple regions, each with several firms. If emissions between regions do not mix, but emissions among firms within a region do mix, a weighted sum damage function would be appropriate. Pollution problems falling into this category might include water pollution, local air pollution, noise, etc.

The above three possibilities describe most of the common pollutants and are most relevant for policy design. It is in fact difficult to imagine a realistic situation where the number of firms do not matter (i.e. $D_n(n,e) = 0$) so that all permits should be free.[8] Further, it would be interesting to identify a pollutant whose damage function satisfies $\varepsilon_n^D > \varepsilon_e^D$ so that $e_0^* < 0$. So far our effort at this has failed.

3 Discussion and Conclusion

In this paper, we have demonstrated that when permits affect the entry and exit decisions of competitive firms, all permits should not necessarily be distributed free of charge. In particular, depending on the nature of the pollutant, an optimal share of the permits should be auctioned with others freely distributed to ensure long-run efficiency. All of the permits should be auctioned when the pollution damage depends only on the aggregate emission. But for pollutants that cause localized damages, some of the permits should be free.

[8] After some thought, we did come up with a restrictive situation. Suppose certain zoning regulations stipulate that all entry and exit activities occur in regions where the pollution causes no damage at all. Then $D_n = 0$ and free permits are efficient. However, since we assumed identical firms, having a special region where firms' emissions do not cause pollution damage is not entirely consistent with our assumption.

Our model recognizes that choosing the proportion of free permits provides the regulatory authority with a policy tool in addition to the total number of permits. In the case of perfect competition, controlling the proportion of free permits allows the government to achieve long-run efficiency. Our results can be extended to the case of imperfect competition in the output market. For example, Katsoulacos and Xepapadeas (1995) considered Pigouvian taxation in a monopolist competitive market, and concluded that an additional policy tool of fixed transfers to firms improves welfare. Such a transfer could be achieved by controlling the proportion of free permits in the context of our model.

In discussing the implications of pollution abatement subsidies, Baumol and Oates (1988) noted that a subsidy will not lead to long-run inefficiency if there is a fixed factor in the industry that captures all the rents due to the subsidy. An example would be agriculture with limited land, where any subsidy will be capitalized into the land value. The same qualification also applies to our model. In fact, if the fixed factor is fully employed, no additional entry can occur without buying out existing firms owning this scarce factor. Thus, the existence of a fixed factor rules out entry possibilities, making subsidies irrelevant for long-run decisions. However, since pollution problems are often associated with more than one industry, a common fixed factor will not often exist. Even land does not qualify as a fixed factor once substitution between urban, industrial, and agricultural uses is recognized.

Our findings have important implications for designing future marketable permit systems. For example, the Kyoto Protocol calls for global carbon trading where permits are to be freely distributed. To the extent that carbon dioxide is a global pollutant, our paper suggests that all permits should be auctioned. Otherwise, when countries expect that a free permit system is to be adopted, entry may occur in order to influence the amount of permits a country will obtain. If this response leads to more firms entering polluting industries, the efficiency of the permit system will be compromised.

At a time when marketable permits systems have entered the realm of viable policy tools, it is important that economists have careful theoretical backing to their policy recommendations. In contrast to the conventional wisdom that the initial permits can be freely allotted to firms based on politically expeditious grounds, our results demonstrate that long-run efficiency dictates that some, none, or all of the initial permits be auctioned, depending generally on the characteristics of the damage function. A challenge for policy makers is to figure out a middle ground in permit allocation between economic efficiency and political feasibility.

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