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Permits, Auctions and Output

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Abstract

In this paper, we develop a formal model that combines point-source emitters of waste, with landholders that can provide pollution-offset activities, in one 'environment economy'. We use the model to demonstrate the societal benefits of such a system relative to a stand-alone tradable permit scheme. In the model we explicitly consider the effect of the scheme on point-source emitters' output.

1.0 Introduction

In this paper develop a model that integrates three main groups, or players, to improve environmental outcomes: an *agency* that tries to obtain improved environmental outcomes at minimum economic cost; *point-source emitters* whose pollution is (relatively) easily monitored; and *landholders* who also pollute, but can provide public goods through land management. We develop a formal model that illustrates the benefits of combining a tradable emission permits system (suitable for point source emitters) with auctions of land management for landholders, as proposed by Stoneham, Duke and Chaudhri (2000).

In this introduction, we shall briefly review key elements of tradable emission permits (TEPs) and auctions for land management, and then introduce a model in which these mechanisms operate together. This model will be formalised in sections 2 and 3 of the paper. In Section 4 we discuss extensions of the model. In Section 5 we provide concluding comments.

1.1 Tradable Emissions Permits

A tradable permit system is a mechanism that can regulate aggregate pollution from point-source emitters (PSEs). This mechanism limits the total quantity of pollution emitted into a region (airshed or watershed) within a given time period. The limit is termed a 'cap'. Shares of the cap (permits) are apportioned between PSEs such that each has a property right over part of the aggregate pollution limit. The cap turns these permits into valued inputs for the PSEs: pollution permits confer to the PSE the benefit of emitting a given quantity of pollution. If permits are tradable, then profit maximising PSEs will trade them so as to minimise the cost of controlling pollution.

PSEs will hold permits up to the point where the marginal cost of pollution (the permit price) equals marginal profit from the polluting activity[1].

Montgomery (1972) argues that—in the presence of heterogenous firms—a tradable permits system can produce a given amount of pollution (the cap) with lower cost to society than a command and control system. In a tradable permit system, each firm can use private information to decide on its profit-maximising combination of output, and pollution (and hence permits). It would be very difficult for a central agency to discover this information.

If a firm can reduce pollution in-house (abate), then it has three options in response to a tradable permit system: hold pollution permits; abate; or some combination of the two. A tradable permit system creates flexibility for PSEs to decide on its profit maximising combination of abatement and permit holdings. PSEs who find it relatively costly to abate will elect to hold more permits, *ceteris paribus*[2]. PSEs who find it relatively cheaper to abate will hold less permits, *ceteris paribus*. In equilibrium, each PSE's marginal abatement cost will equal the price of permits, since no firm would undertake abatement if it were relatively more costly than purchasing a permit in the marketplace, assuming zero transaction costs (Tietenberg 1985)[3].

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[1] We have not yet mentioned abatement, but we will discuss this below.

[2] PSEs are assumed to be price takers in the permit market.

[3] In Australia the Murray Darling Basin Commission allows trading of water entitlements drawn from the Murray River System, and the New South Wales Environmental Protection Authority allows trading of salt export opportunities in the Hunter Valley. Examples of tradable permit systems in operation in the US include: the United States Environmental Protection Agency's sulphur dioxide trading scheme, operated under the Clean Air Act (1990); RECLAIM (Regional Clean Air Incentives Market) which operates in Southern California and regulates nitrogen and sulphur dioxides.

Firms undertaking abatement and buying permits suffer an increase in costs relative to the pre-policy stage; producer surplus is reduced. The burden faced by polluters depends on the price of permits and abatement. Clearly, a reduction in permit price, or abatement costs (ie, a reduction in the cost of pollution) increases producer surplus.

1.2 Auctions for Land-use Change and the provision of pollution mitigation units by landholders.

An agency dealing with environmental problems will have to effectively deal with PSEs, perhaps using a tradable permit scheme, but it will also have to deal with a range of environmental problems that stem from nonpoint (for example, farmers) land management practices. These include rising salt and nutrient levels in rivers, and the destruction of remnant vegetation and dryland salinity. In some cases *multiple benefits*, such as improved water quality *and* pollution-reduction can be gained from a landholder implementing one land-use change (for example, shifting a farmer from crop production to the re-establishment of native vegetation along riparian zones).

The environmental agency could try to buy land management services by giving fixed payments to landholders. However, fixed payments are costly to the agency because they do not account for differences in landholders' opportunity cost of environmental good provision: landholders are heterogenous but fixed payments treat them as homogenous. Therefore, fixed payments will over award landholders with low marginal cost of mitigation. Often, the agency will not have, at its disposal, information about each landholder's marginal cost of land management. However, each landholder may who know his own marginal cost—there is an asymmetric information problem.

The agency can employ an auction mechanism to reveal each landholder's marginal cost (Latacz-Lohmann and Van der Hamsvoort 1997). The agency can call for land-use change bids from landholders. Landholders submit their bids to the agency. The bids represent the minimum remuneration landholders require to provide certain activities. Landholders compete against one another for acceptance of their bid by the agency.

A *well-designed* auction can reveal the minimum remuneration required by different landholders to provide land management. The minimum remuneration required by each landholder is his perceived cost for providing the environmental good, as opposed to continuing with previous activities. These activities could be things such as recreation and production. For a profit maximising landholder, this opportunity cost would equal his profit forgone from environmental service provision.

1.3 Tradable Emissions Permits plus Land-use change auctions

If an environmental agency purchases land management—to derive public goods—from landholders, then it may find that it also effects pollution reduction; for example, one land management change may have the effect of producing improved water quality, and a reduction in pollution.

The beneficiary of public good provision is the general community.

If a tradable permit system were operating concurrently with the agency's land management auction, then the reduction in pollution—which is a by-product of the auction—may be valuable to PSEs[4]. If the units of pollution reduction, or *mitigation*, can be turned into saleable goods, then PSEs may benefit: they may be able to purchase these pollution offsets. In other words, a PSE would be able to pollute more

than their permit holding by buying pollution offsets, or mitigation units, produced by landholders.

Seen in this way, the land management auction has the potential to provide joint production of public and private goods. The general community benefits from the public good, and PSEs benefit from the private good. If landholders can produce so called 'mitigation units' cost-effectively—that is, at a price lower than the price of tradable permtis—then PSEs will find it worthwhile to buy them. In this paper, we call the aggregate of all pollution units traded—ie, permit plus mitigation units—pollution *credits*.

Randall and Taylor (2000) discuss several examples in the US where point and nonpoint firms trade pollution credits. In two of these—the Tar-Pamlico River Basin of North Carolina; and Boulder Creek Colorado—PSEs purchase the right to pollute more, by paying landholders to pollute less. Stoneham and Chaudhri (2000) discuss the possibility of joining PSEs who are engaged in a tradable emissions market, with landholders who are engaged in a land management auction.

The model we develop, in sections 2 and 3, extends the possible set of pollution control options for PSEs by engaging landholders in pollution mitigation provision. The auction provides an additional supply of pollution credits and therefore reduces the price of credits allowing PSEs to increase commodity output, but without increasing aggregate pollution. We assume that the agency on-sells mitigation units to PSEs at a fixed price.

Throughout the paper we assume that mitigation credits are perfect substitutes for pollution permits: a PSE can produce one unit of pollution as long it holds a permit, or

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[4] This assumes the agency can monitor the reduction in pollution. We discuss the costs incurred by the agency in monitoring and enforcement in Section 4.2

mitigation credit, for that unit. The contribution of this paper is that we illustrate the nature of the welfare gains from combining landholders' supply of mitigation units, with the demand by PSEs, given that a tradable permit market is operating for the PSEs.

The auction mechanism enables the agency to pay each landholder her opportunity cost of mitigation provision; the auction allows the agency to perfectly price discriminate in a monopsony fashion. Therefore, landholders receive no producer surplus from supplying mitigation units; they are indifferent between providing mitigation units or otherwise. Since the agency pays landholders their opportunity cost, but sells pollution credits at a fixed price, it receives a positive economic profit on all units of mitigation, up to the marginal unit; where the cost of mitigation equals the permit price (on this, see Stoneham, Duke and Chaudhri 2000). This positive economic profit is eroded or eliminated when transaction costs are incurred in the transfer of mitigation credits from landholders to PSEs. When the marginal transaction cost exceeds the marginal cost of abatement, the joint scheme should be abandoned.

2.0 The Permit Market

2.1 Assumptions

We start with PSEs that compete in a perfectly competitive market. There are $N>0$ homogeneous firms, that produce one product in the relevant region. Initially N is equal to N_0. (We provide a Table with notation in Appendix 1. Throughout the paper we will use subscripts to denote specific values of the variables in question.)

The market price for PSEs' output is $P>0$. Given the price of output, each firm produces output quantity, $q>0$ each time period—which we assume to be one year.

These firms wholly supply the relevant market with this product. If the price of output is initially P_0, then each firm determines its output level by maximising short-run profit, π , which is given by:

$$\pi = P_0 q - C(q)$$

where $C(q)$ is a differentiable variable cost function; $C'(q) > 0$, and $C''(q) < 0$. Therefore, each firm has a marginal profit function:

$$\frac{d\pi}{dq} = P_0 - C'(q) \qquad (1)$$

The marginal profit function is illustrated in Figure 1 (all diagrams are given in Appendix 2).

To maximise profits, each firm produces where marginal profit equals zero; where $P_0 = C'(q)$, which is given as q_0 in the diagram. Total short-run profits are given by:

$$\pi_0 = \int_0^{q_0} [P_0 - C'(q)]dq . \qquad (2)$$

Aggregate short run profits, $N\pi$ are equal to total producer surplus in the market, PS. For each firm, short run profits are the returns to the fixed factor; these profits just offset fixed costs, F. Therefore, in equilibrium each firm makes zero economic profits: $\int_0^{q_0} [P_0 - C'(q)]dq = F_0$. If aggregate production is denoted by Q, and each firm produces q_0, the specific level of aggregate production is given by $Q_0=N_0q_0$.

In initial equilibrium firms produce, in aggregate, B units of pollution. We assume that there is a relationship between pollution and output such that, $B=\alpha Q$, where $\alpha>0$. For simplicity, we assume that $\alpha=1$. Further, we assume that pollution is equally

distributed over the relevant region, ie, we assume that the location of firms doesn't matter with respect to pollution damage[5].

2.2 Introduction of the Scheme

The environmental agency decides that pollution is unacceptably high and that it will therefore introduce pollution credits, b. PSEs will then have to hold a pollution credit for every unit of pollution they emit per year. Initially, pollution credits can only be held in the form of permits. The number of permits issued by the agency for the first year, b_{cap}, is less than what PSE's total pollution would be in the absence of an environmental policy ($b_{cap}<Q_0$). Firms that wish to stay in the industry are faced with several options: abate, buy permits, or both.

We assume that firms must pay a yearly rental for each permit. Therefore, there is no initial 'grandfathering' of permits in our model—a situation that is common where some agency (usually government) allocates permits with some permanent property right to the relevant firms in the industry, free of charge.

We will consider the reaction of firms to the introduction of a permit scheme in several steps. Firstly we will consider a representative firm's reaction when the only option they have is to tackle pollution via abatement. Secondly, we will consider a

[5] If free trade (in permits) is allowed but pollutants do not spread uniformly through the region (for example nitrogen, phosphorous, salt) then hotspots (geographic concentration of pollutants) can arise. Montgomery (1972) and Tietenberg (1995) provide trading designs that exogenously impose trading rules to limit mutually beneficial trading in line with environmental objectives. The U.S Sulphur Dioxide Trading Scheme employs a trading ratio to reflect the marginal damage of an additional unit of pollution in different locations (Hahn and Foster (1995)). The Hunter River Trading Scheme Australia uses water flow and location based emission opportunities for managing salt loads.

firm's response when its only option is to buy permits. We will then consider how a firm responds to the scheme when it can both abate and buy permits.

2.2.1 Abatement

We assume that each PSE can eliminate pollution by undertaking some (in-house) abatement activity. We assume that a unit of abatement will eliminate the first unit of pollution, two units of abatement will eliminate two units of pollution, etc. The firm incurs a cost when abating, equal to $A(q)$. We assume that the cost of abatement rises in q; $A'(q) > 0$.

If the firm only undertakes abatement—and doesn't buy permits—then it equates the marginal cost of abatement to its marginal profit function given in (1). Therefore: $P_0 - C'(q) = A'(q)$. This is shown diagramatically in Figure 2. We assume that there are no fixed costs to abatement; $A(0) = 0$.

In Figure 2, the firm must reduce output relative to the pre-abatement level because of the additional cost incurred per unit of production; the profit maximising condition becomes: $P_0 = C'(q) + A'(q)$. The solution to this generic problem is denoted by the quantity of abatement activity, A. Given price, P_0, we denote this solution by $A_0 < q_0$. The cost of abating the last unit is $A'(A_0)$[6].

[6] In this new position, the firm is no longer adequately covering fixed costs—ie, the firm is no longer viable in the long term, *ceteris paribus.* We will consider the implications of this below.

2.2.2 Permits

Now we consider the case where a PSE must counter pollution by complying with a tradable permit system, but the PSE does *not* have access to any abatement technology.

We assume that each PSE is too small to affect the market for permits, and must therefore accept the price of permits, t, as given. (We talk about the determination of t below, in Section 2.2.6). The firm faces a total cost of permits for any output level, q, equal to tq. The firm's profit function is therefore $\pi = P - C(q) - tq$. The profit maximising condition for the firm is: $P = C'(q) + t$.

2.2.3 The Firm's Marginal Cost-of-Pollution Curve

When the firm has two options to counter the pollution policy—abatement *and* permits—then it will minimise the marginal cost of pollution control given any level of output. When the cost of abatement is lower than the cost of pollution credits (permits)— $A'(q) < t$ —then the firm prefers abatement. When the price of pollution credits is below the marginal cost of abatement — $A'(q) > t$ —then the firm prefers permits. The firm's marginal cost of pollution function, C_p, can be written as:

$$C_p = DumA'(q) + (1 - Dum)t .$$

Where *Dum* is a dummy variable that is 1 if $A'(q)<t$ and zero otherwise. The firm will produce up to the point where the (potentially kinked) marginal cost-of-pollution function, C_p, is equal to (1); $P_0 - C(q) = DumA'(q) + (1 - Dum)t$. We call the output level that solves this equation, f—which may be comprised of output units that are abated, and those that for which the firm holds permits. (Below, in Section **Y**, we will introduce the possibility that f be partly comprised of mitigated units).

In Figure 3(a) we give an example where the firm chooses to abate only, and *not* buy permits. We denote the output level that solves the equation $A'(q) = t$ by a (also shown in Figure 3(a)). The firm will choose to produce $f_e<a$. We can see that through the output range, zero through f_e, $t_e>A'(q)$. Therefore, the relevant marginal cost of abatement function is $C_p=A'(q)$.

Conversely, in Figure 3(b) we show an example where the firm will only buy permits; and undertake no abatement. The firm produces f_g units of output. For all units of production between zero and f_g, $t_g <A'(0)$; the relevant marginal cost-of-pollution function is $C_p=t_g$. Since the firm must hold f_g permits, it incurs a total permit cost of $f_g t_g$.

However, there are cases where the firm will utilise both abatement and permits in response to the pollution policy. We show this situation in Figure 4(a). In the figure, there are *profitable* units of production where (i) abatement is initially cheaper than permits; and (ii) the marginal abatement curve then rises above the level of the permit price. The firm's C_p curve is given by the heavy line.

2.2.4 The Firm's Demand for Permits

Knowing the firm's C_p curve, we can determine its demand for permits. At any pollution credit (permit) price $t > A'(A)$, the firm will not buy permits; the firm's quantity of permits, p, equals zero. At any $t < A'(A)$, where the marginal cost of buying permits is less than the marginal cost of using abatement, the firm will demand some positive quantity of permits, $p(t) = f - a$. Figure 4(a) shows one particular case: the firm abates a_0 units of pollution, and buys $p_0=f_0-a_0$ permits.

2.2.5 Aggregate Demand for Permits

At any $t < A'(A)$, we know the firm's demand for permits given any commodity price, $p(t)|P$. Since we also know the number of firms, N, we can derive the aggregate demand for pollution credits, $b_d=N\{p(t)|P\}$—the horizontal summation of each firm's demand. This is shown in Figure 4(b).

2.2.6 Imposition of the Cap and the determination of the Permit Price

Until now, we have been talking about the permit price, t, without mentioning how it is determined. We can, however, derive t given that we know each firm's derived demand for permits, and hence the aggregate demand for permits. The only additional information we need is the level of permit supply.

The level of permit supply is determined by the environmental agency. The agency introduces a fixed supply of permits, $b_{cap}<B=Q_0$. Since supply is fixed, the price of permits adjusts to equate aggregate supply and aggregate demand: $b_{cap}=N\{p(t)|P\}$. An example is given in Figure 4(b): the price of permits, t_0, equates aggregate demand to the agency's cap level, b_{cap}.

3.0 The Auction Market: Additional Pollution Credits Through Mitigation

3.1 Assumptions about Mitigation

We now examine the benefits of using—in addition to the above permit scheme—an auction mechanism to provide mitigation activities. We denote landholders' aggregate mitigation *by M*. The value of any unit of mitigation activity is that it offsets, or absorbs, one unit of pollution or waste. This might occur, for example, because a landholder reduces pollution by one unit.

We assume that the production of mitigation units is facilitated by some environmental agency. The agency purchases land management from landholders—perhaps in order to derive public good benefits—and this produces mitigation credits from landholders. The agency then on-sells these mitigation credits to PSEs. Landholders can provide mitigation credits by undertaking some land-use change, such as providing buffer zones near rivers.

Mitigation is another type of pollution credit. Therefore, when mitigation is introduced, PSEs can get pollution credits in two forms: permits or mitigation units. If we denote the aggregate supply of pollution credits as b_s, then we have: $b_s=b_{cap}+M$. Given that pollution rises with output, a permit-plus-mitigation system increases the aggregate supply of pollution credits (we will expand on the value of this below, in Section 3.2).

We assume that the aggregate inverse supply function of mitigation-plus-permit credits is given by $f_s(b)$, where this is a differentiable function; $f_s'(b)>0$. Since mitigation activities augment the *already available* fixed supply of permits then $f_s(b)$ crosses the horizontal axis at $b=b_{cap}$ (Figure 5(b)). The slope of $f_s(b)$—when $b>bcap$—is determined by the marginal cost of landholders' mitigation activities.

Each firms' demand for permits is now converted to a demand for pollution credits—regardless of whether these are in the form of permits, p or mitigated units, m. Therefore, each firm's profit maximising production level is made up of units abated, and those for which a pollution credit is held. Mathematically, we may write: $f=a+p+m$.

3.2 Results in the Permit-plus-Auction System

In the first instance we assume that the agency collects information about demand and supply of mitigation. Theoretically, the agency could solve for firms' aggregate demand for pollution credits in several ways. Firstly, the agency could be thought of as announcing prices $t \in [0, A'(A)]$ to PSEs and taking quantity bids, to reveal the curve $b_d=N\{p(t)|\ P\}$. Secondly, the agency could solve directly for the demand function: since demand is derived given the form of $A'(q)$ and $P\text{-}C'(q)$, if the agency knows the parameters of these functions, it can calculate b_d directly. Either way, once the agency solves for b_d, it can calculate the inverse demand function, $f_d(b)$.

The agency can derive the exact form of the supply curve, $S(t)$, through the auctioning of management agreements for mitigation. Afterwards, it can solve for the inverse supply function, $f_s(b)$. Given good auction design, the agency pays only the marginal cost of each mitigation unit (it perfectly price discriminates).

The agency could then, theoretically, solve for the equilibrium quantity of pollution credits, b_0 via $f_d(b) = f_s(b)$. By substituting back into either f_d or f_s, the agency can solve for equilibrium price of pollution credits, $t_1<t_0$: the additional supply of pollution credits pushes down their price, *ceteris paribus*. The level of pollution credits supply in equilibrium is $b_0 = b_{cap} + M_0$, which is equal to total demand, $b_d=N_0(p_0+m_0)$. See Figure 5(b).

In practice, the agency would probably solve for equilibrium quantities through iteration. Without knowing the exact form of the inverse demand curve, f_d, and therefore not knowing M_0, the agency could choose to buy a conservative level of mitigation units, $M_c<M_0$. The agency would then on-sell these M_c units to PSEs. If the price at which the agency acquires the last unit is less than the equilibrium price of

pollution credits, then the agency knows it can increase supply in the next year, *ceteris paribus.*

Each PSE's response to the permit-plus-auction system is given in Figure 5(a). Given P_0 and t_1, each firm produces $f_1=a_1+p_0+m_0$ (where $m_0 = m_0^1 + m_0^2$). Although the optimal amount of abatement and output for each firm changes—to $a_1<a_0$ and to $f_1>f_0$ respectively—the quantity of permits stays the same at p_0: there is only a fixed supply of permits and the number of firms has not (yet) changed.

The components of m_0— m_0^1 and m_0^2 —reflect two different types of gain to PSEs due to the fall in the pollution credit price: m_0^1 reflects the replacement of relatively costly abatement activity, and m_0^2 reflects the increase in output.

The aggregate pollution level is not solely determined by PSEs: landholders also contribute to aggregate pollution. In Figure 6 we illustrate aggregate pollution before and (immediately) after the scheme . Prior to the beginning of the scheme, aggregate pollution is b_{pre}. This is comprised of two components: pollution from PSEs of N_0q_0; and pollution from landholders of b_{pre} minus N_0q_0.

When the agency implements a cap on PSE pollution at b_{cap}, this reduces PSE and aggregate pollution by z. Suddenly, the right to produce more pollution is valuable to PSEs, giving rise to the demand curve for pollution credits (mitigation), familiar from our previous discussion.

The agency's purchase of mitigation units from landholders gives rise to the supply curve, $f_s(b)$ in Figure 6. Between b_{cap} and b_0, PSEs are willing to purchase mitigation units at a price greater than landholders' opportunity cost of provision. Therefore, the agency can on-sell b_0 minus b_{cap} (=M_0) units of mitigation to PSEs.

The interaction of PSEs and landholders helps to minimise the cost of producing total pollution, b_{post}. Although each PSE has increased their output in the new equilibrium, and hence produced more pollution, the *net* amount of damaging pollution has *not* increased; each firm's additional waste (m_0) has been completely mitigated. Therefore, in aggregate, PSEs are emitting $b_0 > b_{cap}$ units of pollution, but this additional pollution is exactly offset by a reduction in pollution by landholders.

A point worth noting, however, is that if landholders can shift the supply curve—$f_s(b)$—downwards, then aggregate pollution may rise above b_{post}. This might occur, for example, if intensively-polluting industries reap productivity gains through technological improvement, and expand at the expense of other industries.

3.3 The Benefits of a Permit plus Auction System

We are now in a position to analyse the aggregate impacts of the environmental policy on firms, landholders, and the environmental agency. Firstly, we will assume that the number of firms remains constant, at N_0. Then we will look at the impact of a fall in the number of polluting firms.

Holding the number of firms constant, we will consider the impact of the policy on firms' costs and hence producer surplus. We show that the impact on firms' costs is lower in the permit-plus-auction system, than the stand-alone permit system. Secondly, we will analyse the benefits that the policy confers on the environmental agency.

In Section 3.3.2 we relax the assumption that the number of firms remains constant. Specifically we will look at how a fall in the number of firms will impact upon producer surplus, and the environmental agency. We would expect the number of firms to fall since the policy will raise firms' costs.

In Section 3.3.3 we briefly consider distributional issues that are raised by the model.

3.3.1 Results when the Number of Firms Remains Constant

No Pollution Policy: the impact on PSEs

In the absence of a pollution policy, PSEs are able to reap their maximum producer surplus, equal to each firm's profit, by the number of firms:

$$PS_0 = N_0 \pi_0 = N_0 \int_0^{q_0} [P_0 - C'(q)]dq$$

(as given in Section 2.1).

The Permit System: impact on PSEs

When faced with a permit system, PSEs' production is restricted to b_{cap}. The permit policy imposes additional costs on PSEs because they must abate and/or buy permits. Each firm's loss is equal to

$$L_1 = \int_0^{a_0} A'(q)dq + (f_0 - a_0)t_0 + \int_{f_0}^{q_0} [P_0 - C'(q)]dq \,. \qquad (3)$$

Therefore, aggregate firm losses are $N_0 L_1$. The net producer surplus position of firms—compared to the no-permit situation—is therefore:

$PS_1 = N_0(\pi_0 - L_1)$.

The public benefits from a reduction of $N_0 q_0 - b_{cap}$ (=z) units of pollution or waste.

The Permit-plus-Auction System: impact on PSEs

The permit-plus-auction system reduces the loss to each firm, relative to the stand-alone permit scheme. The permit-plus-auction system reduces price of pollution

credits and firms gain for three reasons: they pay less for the permits they already hold; they replace relatively costly abatement with mitigation units; and they expand output. For each firm, this benefit—relative to the stand-alone permit market—is equal to:

$$\Delta\pi = \int_{a_1}^{a_0} [A'(q) - t_1]dq + (t_0 - t_1)p_0 + \int_{f_0}^{f_1} [P_0 - C'(q) - t_1]dq .$$

In aggregate, this change in producer surplus is $\Delta PS = N_0 \Delta\pi$. This will be equal to the area below the aggregate demand curve but above t_1, for the units of production b_{cap} through b_0. This can be formally written as:

$$\Delta PS = \int_{b_{cap}}^{b_0} [f_d(b) - t_1]db .$$

The Permit-plus-Auction System: impact on the Environmental Agency

The environmental agency receives $t_1 M_0$ in revenue, but pays auction costs equal to $\int_{b_{cap}}^{b_0} f_s(b)db$—this is exactly equal to landholders' cost of providing mitigation activities, if the agency can design the auction well enough to perfectly price discriminate. In other words, landholders are theoretically indifferent to the scheme.

The agency makes a net gain, *AS*, equal to $t_1 M_0 - \int_{b_{cap}}^{b_0} f_s(b)db$. This can be thought of as the amount needed to cover the agency's transaction costs (see below) and is shown as the shaded area in Figure 5(b).

3.3.2 Results when the Number of firms Falls

The aggregate results above assume no firm adjustment. However, in the equilibrium position (t_0, f_0) each firm will actually be making losses equal to:

$$L_2 = \int_0^{a_1} [A'(q)]dq + t_1 (f_1 - a_1) + \int_{f_1}^{q_0} [P_0 - C'(q)]dq \,. \qquad (4)$$

Since π_0-L_2<F_0, firms will not be covering fixed costs. Some firms will exit; bringing the number of firms down to N_1<N_0. Since we assumed homogeneous firms, we cannot say *which* firms will exit. However, whichever firms exit, the *aggregate* supply of the commodity will shift to the left, and this will raise the price of the commodity (since we assumed these firms wholly supply the relevant market with the commodity in question). The commodity price rises from P_0 to P_1.

The price rise due to the exit N_1-N_0 firms raises the marginal profit function of the remaining firms. The shift will occur until the increase in profits, just equals the loss given in (4).

If we assume that the policy is implemented, and firm numbers and the price of the commodity instantaneously adjust, then we have a situation where each firm is back to making zero economic profits—where it is just covering fixed costs, F_0.

The effect of firm exit on the aggregate demand for pollution credits is ambiguous. There are two forces at work. Firstly, a lower number of firms *decreases* the aggregate demand for pollution through the parameter N in the aggregate demand function. Holding the form of the function $p(t)$ constant, at say $p_0(t)$, *aggregate demand falls to* $N_1p_0(t)$<$N_0p_0(t)$.

Secondly, the exit of firms produces a leftward shift in the aggregate commodity supply function, and hence causes a rise in price, to P_1>P_0. This *increases* the

demand for permits of each *remaining* firm via the shift in the profit function—the demand for permits of each remaining firm rises to $p_1(t)>p_0(t)$ for any t.

The net outcome on aggregate demand depends on the exact shape of the marginal profit and marginal abatement functions, and the aggregate demand and supply functions. We assume that the net effect on aggregate demand, below $A(A_0)$, is negligible. That is, we assume that the fall in aggregate demand—due to the fall in the number of firms—is exactly equal to the rise in aggregate demand, due to each firm's increased demand for permits. This means that the *aggregate* benefit to firms of the permit-plus-auction system—over a stand-alone permit system—are still given by the calculations shown in the previous section.

Considering firm exit highlights an additional cost of the permit-plus-auction system (or in fact a stand-alone permit system): the rise in output price, P, means that there is a loss in consumer surplus. The total value of the losses—to firms plus consumers—should be offset by a gain in environmental quality for the scheme to be worthwhile: the value of surplus losses provides a shadow price for the environmental gain.

3.3.3 Distributional Issues

There is clearly a re-allocation of property rights in the model. We have presented a scenario where the agency implements a tradable permit system first, and then it on-sells mitigation units—provided by landholders—to PSEs.

The tradable permit system diminishes PSEs' right to pollute, but it does not affect the rights of landholders—the other polluters in our model. Then, with the auction system, landholders are *subsidised* to provide public goods and mitigation units.

Effectively, landholders come out as winners in the model: the property right to pollute has been allocated to them.

In order to get agreement for the policy, the environmental agency would have to be very careful about implementation. If the main thrust of land management is to purchase public goods, then the auction could be seen as a mechanism for cost sharing. Mitigation units are then simply a valuable by-product. Shifting their cost to PSEs in this model may be deemed beneficial by the agency from a budgetary perspective. However, it could also be seen as unfair by PSEs.

4.0 Extending the model

In this section, we consider several ways in which the model could be extended. Firstly we consider the case where PSEs are heterogeneous. Then, we briefly consider transaction costs.

4.1 Heterogeneous Firms

We assumed in the above analysis that all PSEs were homogeneous. This was sufficient to explore the main results from the model. However, one of the main arguments for using a tradable permit system is to take account of differences in firm heterogeneity (see Section 1.1). The ability of firms to make relatively high profits per unit of pollution is dependent upon their total cost functions: $TC=C(q)+F+A(q)+tq$. We assume that firms take t as given. Therefore, each firm's total cost of permits is determined given their production costs $C(q)+F$, and abatement cost, $A(q)$. We consider each of these elements in turn:

4.1.1 Differences in Firms' Production Cost Functions

Firms may have production cost advantages—that is, lower costs—for several reasons: entrepreneurial skill, teamwork, research and development, etc. More efficient firms may have either lower variable costs, or lower fixed costs.

We assume that there are two firms—*i* and *e*. Firm *i* is relatively inefficient with variable cost function, $C_i(q)$. Firm *e* is relatively efficient with variable cost function $C_e(q)$. These result in different marginal profit functions, where for any output, $q>0$, $M\pi_e(q) \geq M\pi_i(q)$. These are represented in Figure 7(a). For simplicity, we assume that there are no abatement technologies (which gives the same result as assuming both firms have the same abatement technology). The aggregate demand for permits, $p_i(t)+p_e(t)$, that results from these marginal profit functions is given in Figure 7(b).

Initially, we consider the effect of a stand-alone permit system. The environmental agency introduces a cap on permits at the level of $b_{cap}=2q_b$. Assuming that each firm cannot influence the market price of permits, there would be a tendency for the price to move to t_0.[7] Figure 7(a) gives each firm's profit-maximising response to this policy. Firm *e* buys more permits than firm *i* ($q_e>q_i$). This could be an equilibrium solution if the firms have different fixed costs: F_e *and* F_i. Each firm's profit is given by $\pi_j = \int_0^{q_j} [P_0 - C_j(q) - t_0]dq$, where $j=i,e$. (5)

This is the relevant solution when firms rent yearly permits from the agency. However, we can also consider the case where firms are initially *allocated* an equal

[7] If there were only two firms, then it is unlikely that they would accept the price of permits as given. However, we use two firms only to illustrate the concepts graphically, which would be cumbersome with greater than two firms.

number of permits—such as in a grandfathering system where each firm gets q_b units ($q_i<q_b<q_e$). If firm *e* receives, *and must use,* the quantity of permits, q_b, then it would produce q_b. However, at price t_0 firm *e* would prefer to expand output to q_e; at q_b the firm makes :

$$\pi_j = \int_0^{q_b} [P_0 - C_j(q) - t_0]dq \ \ (j=e) \qquad (6)$$

which is less than the profits the firm makes in (5). The story is analogous for firm *i* (when $j=i$ in (6)). Therefore, if exchange were allowed, firms would trade because there are benefits to firm *e* of buying additional permits, and benefits to firm *i* of selling permits. At a price of t_0, firm *e* could buy an additional q_e-q_b=q_b-q_i units, that *i* could sell. The gains of trade accruing to the two firms are given by the change in profits to both firms, which can be calculated using equations (5) and (6).

The effects of introducing mitigation credits—through an auction system—are shown in Figure 8. Additional pollution credits reduce their price from t_0 to t_1. Figure 8 shows that both firm *i* and firm *e* increase production: *i* increases production by q_i^n-q_i, but firm *e* increases production by more; q_e^n-q_e. In equilibrium firm *e* holds more permits, and more mitigation credits. The benefits to PSEs of the permit-plus-auction system are:

$$\pi_2 = \int_{q_i}^{q_i^n} [P_0 - C_i(q) - t_1]dq + \int_{q_e}^{q_e^n} [P_0 - C_e(q) - t_1]dq \,. \qquad (7)$$

Therefore, the effect of different cost functions is that—in the equilibrium of a permit-plus-auction system—not all firms will operate at with the same level of output and pollution credits. More efficient firms will produce more, and therefore hold more pollution credits, *ceteris paribus*.

Therefore, when firms cost functions differ, the permit-plus-auction system allows firms with high profit-to-pollution ratios to exploit their advantages: the additional profits obtained by efficient firms and given by the second expression on the right hand side of (7), are relatively larger than the additional profits given by first expression.

The fact that more efficient firms better exploit the permit-plus-auction system is completely analogous to the standard arguments in favour of a tradable permits system: the economic cost of the pollution policy is minimised; and firms' purchases of pollution credits reflect their own information on cost differences, which the agency need not know.

4.1.2 Differences in Abatement Curves.

The results of the above section are analogous to the case where firms have different abatement technologies: firms with lower marginal abatement costs, $A_e'(q)$, will abate more and hence hold fewer pollution credits (f-q_e, instead of f-q_i in Figure 9).

4.1.3 The form of Abatement Technology

There is another interesting aspect of abatement technology: the *form* of the total cost of abatement, $A(q)$. We assumed in the model of Sections 2 and 3 that firms incur abatement cost $A(q)$, and that there were no fixed costs to abatement. Further, we assumed that for each unit of abatement, pollution was *completely* eliminated.

If there are fixed costs of abatement F_A, but $A'(q)$ still rises in q, then the results given in Sections 2 and 3 are largely unchanged. The only addition to the model is that firms must cover total fixed costs of $F+F_A$, rather than just covering F.

Another extension of the model would be the case where abatement units did not completely eliminate pollution. That is, abatement activity might lower—rather than eliminate—pollution per unit of output.

Largely, this assumption still leaves the analysis unchanged: the marginal cost of abatement curve can be interpreted as making a pivotal shift leftwards. We can use Figure 9 to consider this case. Instead of Figure 9 representing two firms with different abatement technologies (as in Section 4.1.2), we can think of it as representing one firm; where $A_e'(q)$ gives the monetary cost of marginal abatement (as before), but $A_i'(q)$ represents *effective* marginal abatement. For example, at a marginal abatement cost of t, the firm undertakes q_e units of abatement, but only eliminates q_i units of pollution. Therefore, the distance q_e-q_i represents pollution that requires pollution credits: the firm must buy total pollution credits equal to f-q_i. The firm's total variable cost (TVC) could be represented by: $TVC=C(f)+A(q_e)+t(f-q_i)$.[8]

4.2 Transaction Costs

In our model, the environmental agency must purchase land management from landholders. Therefore, the agency would need to sign a contract with each landholder, and ensure that she fulfilled the contract terms. There could be significant transaction costs involved implementing such a scheme.

[8] This situation is much easier to tackle mathematically rather than diagrammatically: once the one-to-one nexus between pollution and output is broken, the horizontal axis on our standard firm-level diagram would need to represent both quantities.

Stavins (1995) points out several ways in which economic agents may incur transaction costs when engaging in trade)[9], these are:

a) search and information—firms need to discover and employ their control options and potential trading partners;

b) bargaining and decision—resource costs such as time, legal and insurance;

c) monitoring and enforcement.

Stavins (1995) showed that transaction costs generally increase the total cost of pollution control by creating a wedge between the marginal cost of pollution credits, and the marginal demand for pollution credits. This wedge is equal to the transaction cost incurred on the sale of the last credit. In our model, if the agency incurs the transaction cost, then equilibrium occurs where the marginal willingness to pay for pollution credits (f_d) equals the marginal pollution-credit-plus-transaction cost. Transaction costs will usually reduce the volume of trade in pollution credits[10].

In Figure 10 we show how constant transaction costs affect our model[11]. Over the range of pollution credit supply—from b_{cap} to b_0—the supply function of mitigation

[9] Additional sources of transaction cost are, costs of regulatory delay and any indirect costs, for example, risk perception.

[10] The volume of permit trading will be reduced irrespective of the form the marginal control cost function and marginal transaction cost function take (Stavins (1995)). However in this model as transaction costs are incurred by the agency not the landholder the agency may in the case of decreasing transaction costs increase supply of mitigation credits beyond the zero transaction cost equilibrium.

[11] In this paper, we will only consider constant transaction costs. However, marginal transaction costs may be constant, increasing, or decreasing.

credits shifts upward by the magnitude of the per-unit transaction cost. The resultant supply function is one parallel to f_s, such as f_c. The equilibrium price of pollution credits becomes t_c. The benefit to the agency is now the area AS (see Section 3.3.1) less total transaction costs which have two elements: (i) the per unit rise in supply cost; and (ii) the reduction in the quantity supplied of mitigation credits. The magnitude of total transaction costs is dependent upon the magnitude of the per-unit transaction cost, and the relative slopes of mitigation-demand and mitigation-supply curves.

In the case of constant transaction costs, the permit-plus-auction scheme is never worthwhile if the transaction cost of the first unit is greater than t_2 (see Figure 10). In other words, the scheme is not worthwhile if the per unit transaction cost is greater than the marginal cost of abatement for each PSE.

5.0 Concluding Comments[12]

In this paper, we have discussed a theoretical model where an agency has two aims: to change land use and therefore derive public goods; and to lower the amount of aggregate pollution. The agency does this in a two part process.

First, the agency subjects point source emitters to a tradable permit system. This makes the 'right to pollute' valuable to polluters. Second, the agency purchases land management from landholders. This provides two types of goods: public goods; and the provision of mitigation services.

Mitigation services produced by landholders have value to point-source emitters engaged in a tradable permit system, as long as point-source emitters can purchase

[12] We do not use abbreviations in this section.

mitigation units as offsets for their own pollution; and if the price of these mitigation units is below the (traded) permit price.

Using the model, we demonstrated that there is potentially an economic-surplus gain from combining landholder mitigation and a tradable permit system, given that transaction costs can be kept relatively low. Mitigation services help to provide a surplus benefit because they increase the supply of pollution credits available, allowing point-source emitters to expand output beyond the tradable-permit cap. This decreases the price of pollution credits. This gain can, theoretically, be achieved without an increase in the net amount of damaging pollution—the additional pollution from point source emitters is mitigated by landholders.

However, in order to practically implement the scheme, an environmental agency would need to cross several practical hurdles.

First, the agency would need knowledge about the effectiveness of mitigation activities. In essence, the agency would have to determine either: a) the exact amount pollution by each landholder; or b) an exchange rate between on-land management, and mitigation effectiveness. If the agency chooses the latter, this may vary across regions or land types. External forces such as weather could further complicate the calculation of the exchange rate.

The agency could be conservative in setting the exchange rate (effectively raising the price of mitigation), but this would lower point-source emitters' use of the scheme. Research into the appropriate exchange rates would probably involve large up-front costs in terms of research. However, once established, the exchange rates may be stable over long periods of time.

In our model, the agency purchases mitigation units from landholders via auction, and sells them to PSEs at a fixed price. In reality this may be difficult to maintain in the long run: if landholders can discern which part of their management activities are for mitigation purposes, then they would essentially know the upper limit on their bid (what Latacz Lohmann and Van der Hamsvoort call the bid cap). This would lead, as Latacz Lohmann and Van der Hamsvoort argue, to bids that equal the market price of mitigation activities; the agency would no longer be able to price discriminate.

There are several re-formulations of our model that can handle this problem: (a) direct sale of mitigation units from landholders to point-source emitters, and (b) auctioning for the supply, *and* purchase of mitigation units.

With option (a), the agency would be like a stock-exchange, which could recover its costs of operation through trading fees. In this case, the possibility to target multiple benefits is forsaken since point-source emitters are concerned only with mitigation units (and not, for example, biodiversity values). However, the public can free ride on whatever biodiversity benefits result from mitigation.

With option (b), point-source emitters would have to submit sealed bids to the agency for mitigation units. To the extent that bids on both the supply and demand side can be kept as private information (only the bidder and the agency would know the price of any one bid) then the agency would price discriminate on both sides of the market: point-source emitters would purchase mitigation units with a maximum willingness to pay, and landholders would sell services at their opportunity cost. To function properly however, this would require that neither side of the market know the price of trades on the other side.

6.0 References

Atkinson.S.E. 'Tradable Permits: Restrictions on least-Cost Solutions', in *Economic Instruments for Air Pollution Control*. Klaassen.G.F and R.Finn eds. Economy and Environment series, vol.9. Dodrecht and Boston.

Cason.T.N. and Plott.C.R. (1996) 'EPA's New Emissions Trading Mechanism: A Laboratory Evaluation', *Journal of Environmental Economics and Management*, vol.30 pp.133-160.

Environmental Protection Authority, New South Wales, Australia (year??) *Environmental Economic Series Hunter River Salinity Trading Scheme Guideline and Rule Book*, Northern Regions, legal Services, and Economics and Reporting Branches.

Hahn.R.W and Foster.V. (1995) 'Designing more Efficient Markets: Lessons from Los Angeles Smog Control, *Journal of Law and Economics*, vol.38, pp.19-47.

Ingram, B. (1998), 'Audit of Phosphorus effluent from trout farms in the Goulburn-Broken catchment', A report to Fisheries Victoria.

Krupnick.A.K. and McConnell.V. (1999) 'Cost-Effective NOx Control in the Eastern U.S.' A paper prepared for the Association of Environmental and Resource Economists *Workshop on Market-based Instruments for Environmental Control*, Harvard University, July 1999.

Latacz-Lohmann, U. and Van der Hamsvoort, C. (1997), 'Auctioning Conservation Contracts: A Theoretical Analysis and Application', *American Journal of Agricultural Economics*, vol. 79 no. 2 pp. 407-18.

Mongomery.W.D. (1972) Markets in Licences and Efficient Pollution Control Programs, *Journal of Economic Theory* vol. 5 pp.395-418.

Parslow,J., Sokolov.S., and Murray.S. (1999), *Port Phillip Bay – Baseline, monitoring and anlaysis for nitrogen load reductions – Final Report* CSIRO Marine Research August 1999.

Stavins R.N. (1995) 'Transaction Costs and Tradable Permits', *Journal of Environmental Economics and Management* vol.29 pp.133-148.

Stoneham, G. and Chaudhri, V. (2000), The Role for Auctions in Tradable Emission Markets, *Paper presented at the Australian Agricultural and Resource Economics Conference*, Sydney.

Stoneham, G., Crowe, M., Platt, S., Chaudhri, V., Soligo, J. and Strappazzon, L. (2000), Mechanisms for Biodiversity Conservation on Private Land, *Department of Natural Resources and Environment, Victoria, Australia.* ISBN: 0 7311 4572 0.

Stoneham, G., Duke, C. and Chaudhri, V. (2000), Policy Mechanism Selection for Environmental Management, *NRE Economics Branch Working Paper*.

Tietenberg.T. (1995) 'Tradable permits for Pollution Control when Emission Location matters: What have we learned?' *Environmental and Resource Economics*, vol.5 pp.95-113.

Tietenberg.T.H. (1985), *Emissions Trading an Exercise in Reforming Pollution Policy,* Resources for the Future Inc., Washington DC.

Appendix 1: Notation

firm's output level	q
price of output	P
firm's total cost	$C(q)$
firm's short run profit (=firm's producer surplus)	π
firm's fixed costs	F
number of polluting firms	N
firm's total cost of abatement	$A(q)$
firm's level of abatement	a
price of permits	t
firm's demand for permits	$p(t)$
firm's profit maximising level of output when facing a pollution policy	f
firm's demand for mitigation	m
aggregate mitigation units	M
aggregate pollution credits	b
cap on aggregate pollution permits	b_{cap}
aggregate demand for pollution credits	$b_d(t)$
(inverse) aggregate demand for pollution credits	$f_d(b)$
(inverse) aggregate supply of pollution credits	$fs(b)$

Appendix 2: Diagrams

Figure 1

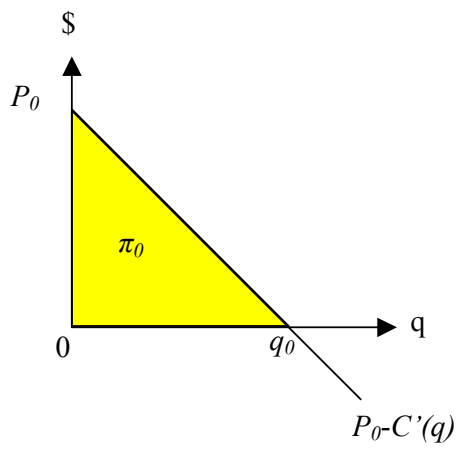

Figure 2

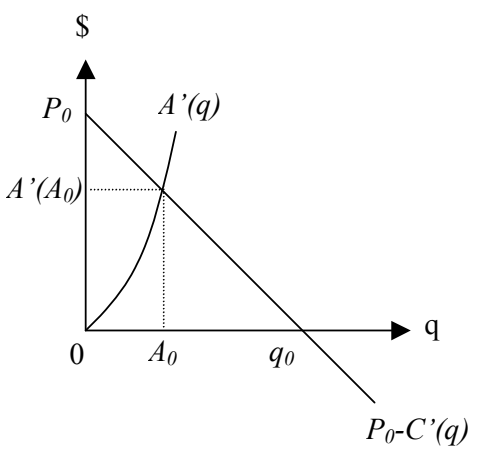

Figure 3

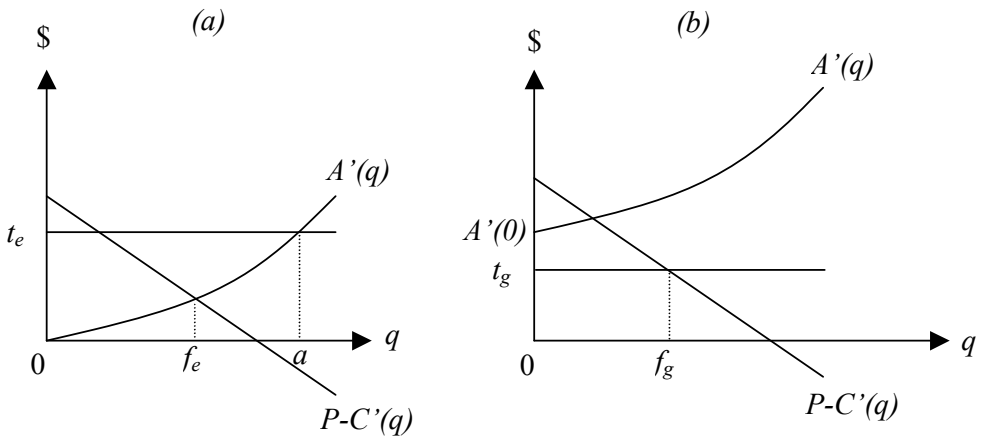

Figure 4

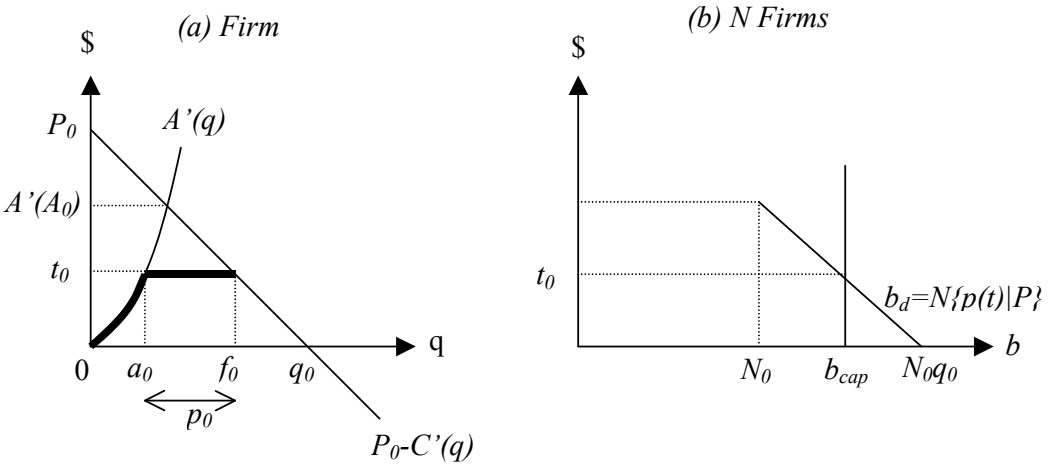

Figure 5

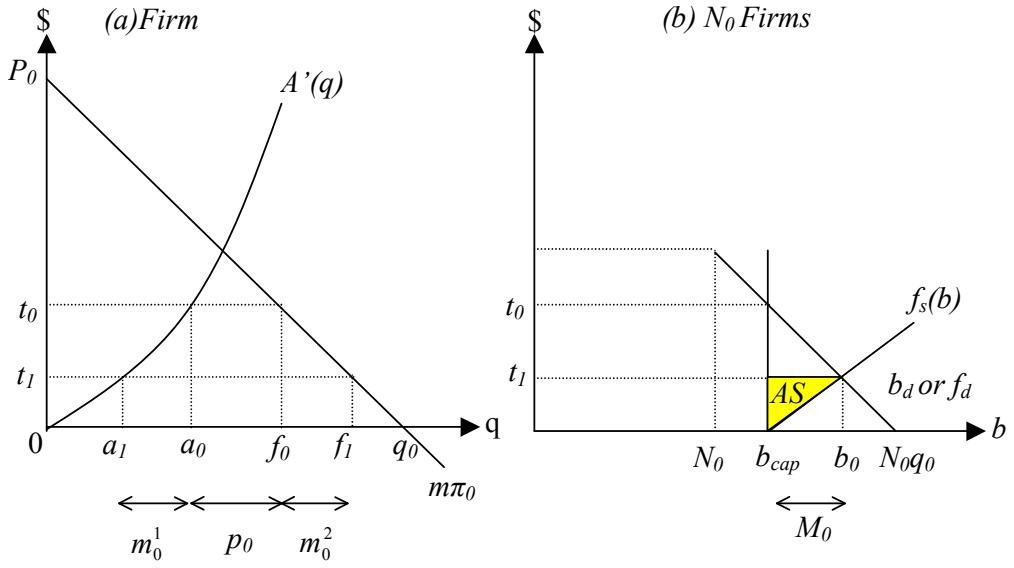

Figure 6

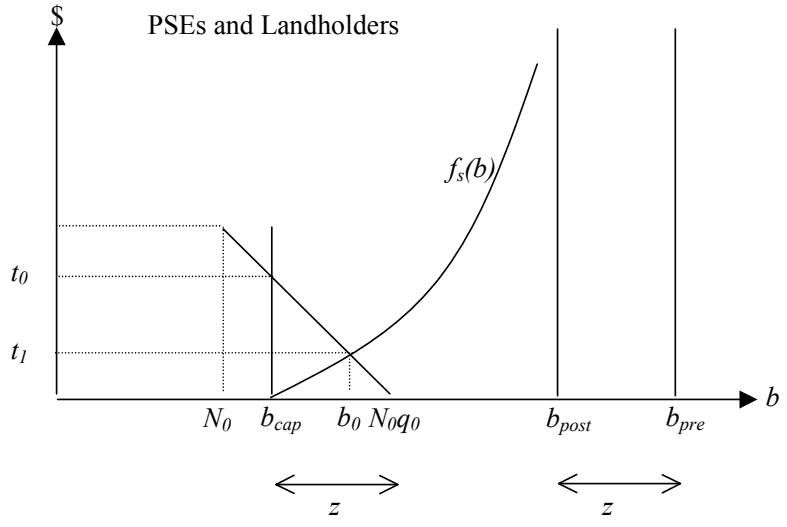

Figure 7

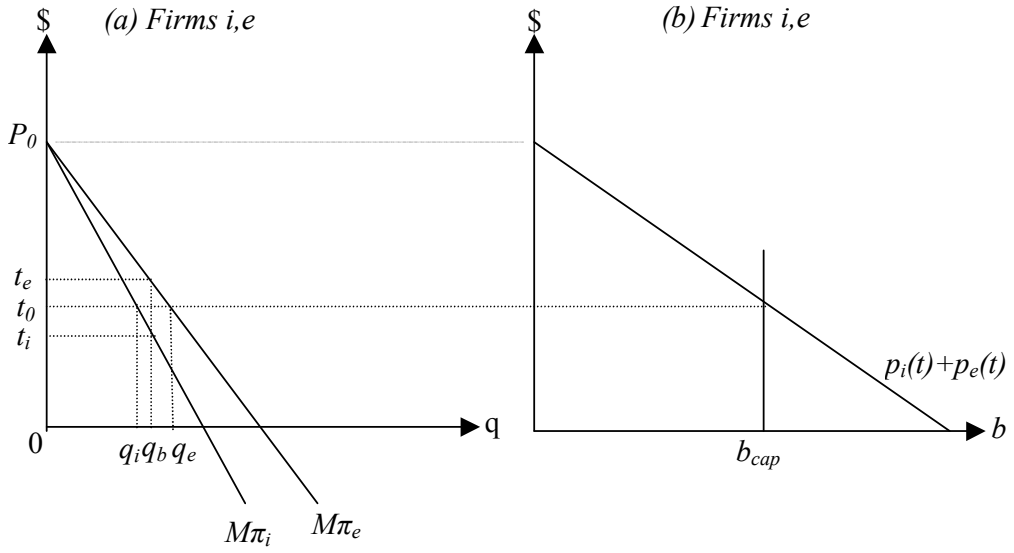

Figure 8

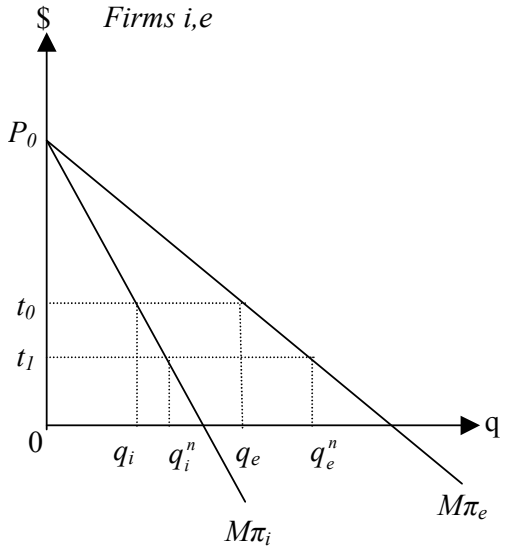

Figure 9

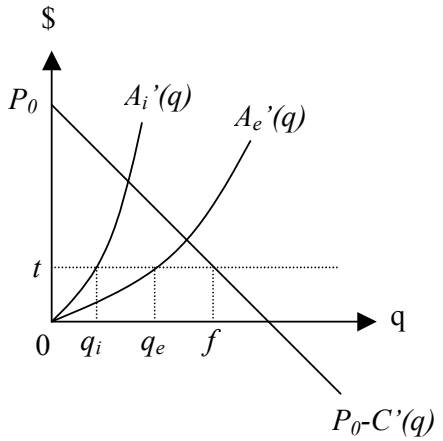

Figure 10