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Vournas, Stylianos

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Stylianos Vournas and Panos Lorentziadis
University of La Verne, Athens Campus.

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Technology Replacement Induced by Government Subsidy

Panos L. Lorentziadis and Stylianos G. Vournas

University of La Verne, Athens Campus, Greece

ABSTRACT

Governments are expected to subsidy activities that would improve environmental conditions. In this respect, subsidies promoting the spread of new environment friendly technology are in effect in most parts of the world. In urban areas, automobile exhaustion gases is a major source of air pollution. Technological efforts aim to either reduce the pollution effect of gasoline or to develop alternative energy sources. As an example, in the early nineties, the Greek Government offered significant tax reduction for the acquisition of new automobiles that use unleaded gas. The favorable tax treatment benefited only those who would withdraw from circulation their old leaded-gasoline car. As a result, the number of old (conventional technology) cars was drastically reduced. In the future, tax incentives and/or subsidies to promote the employment of environment-wise innovations are expected to become common practice, in a large number of countries. A model is developed to determine the appropriate subsidy level that induces the replacement of all existing old-technology units within a specified time period. Alternatively, given the subsidy level, the model allows the determination of the required time period. The proposed method could be used to assess the effectiveness of subsidy-based policies in the promotion of low pollution vehicles.

KEY WORDS: Technology Replacement, Subsidy, Environment, Externality

1. Externalities and Remedies

More attention has been paid to externalities in production than in consumption in both, theoretical analyses and empirical studies. Textbook examples usually refer to a hypothetical industrial unit that pollutes the water of a near-by river, and most applied works try to estimate the cost on environment due to manufacturing or construction projects.

It is claimed that private bargaining can deal with the problem of externalities. The theoretical base is the so called Coase theorem, which implies that an efficient level of output will be reached independently of whether there is a financial transfer from the polluter to the one that suffers the damages, or the first is paid by the latter to reduce damages. Apparently income distribution will be heavily affected but private negotiations would lead to an efficient solution and no government intervention would be required. This two-party model relies on assumptions such as negligible bargaining cost and well defined property rights.

However, society cannot fully depend on the Coase theorem. Negotiations at sufficiently low cost are not realistic if thousands or millions of people are involved. Additionally, the owners of the resource cannot always identify the source of the damage, neither can legally defend their rights. The example of clean air, a typical public good, is often cited; property rights cannot be easily assigned to particular groups, neither the hypothetical owners of this resource would be able to distinguish among the hundreds or thousands of potential polluters.

Government action is, therefore, inevitable. The issue of whether taxes on the release of pollution and subsidies on pollution abatement may achieve an identical solution as personal transfer payments has generated academic interest (Raymond Palmquist,1990). The direction of the impact is, however, unquestionable.

The application of these instruments is not restricted to confront production externalities. In fact, certain sales taxes and, in particular, excise taxes are justified, in the framework of welfare economics, by the presence of negative externalities in consumption. In principle, economic efficiency requires a tax upon the product whose consumption generates a cost which is not included in its price. By the same token, subsidies are justified if total benefits from the consumption of a product exceed its market price.

Societies and governments alike have demonstrated concern for improved environmental conditions. A number of measures has been taken towards this end, although the desired results are far from being fully achieved. With respect to air pollution, for instance, the Greek government offered a significant tax reduction for the acquisition of new cars that use unleaded gas in the early nineties. Currently in Italy, a new car can be purchased at a reduced price, provided that plates of an older than ten year car are handed-in. This policy is considered very successful and may be extended beyond the initially set period. Furthermore, the European Union is determined to fully abolish the use of leaded gasoline by the end of the century.

2. The Theoretical Background

This interest motivated the creation of the model presented in this paper, which can be applied in a number of consumption activities with negative externalities. Our first thought, however, was the application of the model in the protection of the most obvious public good, clean air, from car emissions, an activity in which we all have our fair share. Automobile exhaustion gases constitute, undoubtedly, the largest consumption externality.

In brief, our model assumes that new technology units (e.g cars) are much more environment friendly than old ones. To induce the purchase of new technology the government offers a subsidy, whose level has to be determined, to buyers who retire a conventional technology unit.

With respect to the theoretical underpinnings certain observations can be made. Here, the instrument employed for pollution abatement is a subsidy. Taxes and subsidies are usually considered as alternative tools, although certain authors express their preference for taxes (Anthony Fisher, 1988). Frequently their choice is based on a potential disadvantage of a subsidy; it may have almost unlimited financial consequences on the government budget. More specifically, a subsidy may induce new entrants to an activity who, otherwise, would not find it profitable to get involved. As a result both, the number of polluters and total pollution, may increase in the long run.

In our model, however, the number of subsidy beneficiaries is limited and cannot exceed that of existing old technology units. As an example, government money is not received unless an old technology car is withdrawn from circulation.

In textbooks the impact of subsidies is on the supply curve. However, here the subsidy is given to consumers, not producers, causing a shift up and to the right of the demand curve. The vertical distance between the two curves, the old and new (effective) demand is equal to the amount of the subsidy. Assuming a constant supply curve, the result would be an increase in both quantity and price. The magnitude of the increases, as well as, the incidence will be determined by the relative elasticities of both curves.

It is rather realistic to claim that the supply curve of cars for a typical European economy might be, in practice, perfectly elastic. Car industries produce at large scale and their models are sold in a large number of countries. This is also true for a number of technology incorporating products. If, during a period, in a particular economy, say of the size of the Greek one or even larger, the demand increases for some reason, the additional quantity can be supplied without raising costs and prices; it represents a small fraction of the industry' s potential. Therefore, in the framework of a perfectly elastic supply, the price will not be affected and buyers will benefit the full amount of the subsidy.

Our model considers a fixed per unit subsidy (not *ad valoren*). Therefore, the vertical distance of the two demand curves will be equal for their entire range.

3. Development of the model

Let N_0 be the initial number of old technology units (before any subsidy is introduced). Suppose that in the market there are k models of new technology units. Their price is p_1, p_2,…, p_k.

We call $q_{0,i}(.)$ the demand curve of the i th model, i.e. the quantity demanded at different price levels.
The quantity demanded refers to consumers who are also owners of old technology units.
It is clear that the number of new technology units which will be bought by owners of old technology units will be given by:

$$\sum_{i=1}^{\kappa} q_{0,i}(p_i)$$

Since a subsidy has not yet been introduced, the new technology units, that are purchased, may or may not replace existing old technology units. Therefore, the decrease of the number of old technology units can not be specified.

Suppose, now, that a subsidy is introduced. In particular, a buyer of a new technology unit receives a subsidy of an amount α, provided that an old technology unit is withdrawn.
As explained earlier, the impact of the subsidy on the price will be negligible. Note that a purchase of a new technology unit, made by an owner of old technology unit, is automatically equivalent to a withdrawal of an old technology unit.
The units of new technology which will be acquired by owners of old technology units will be:

$$\sum_{i=1}^{\kappa} q_{0,i}(p_i-\alpha)$$

At the same time, another market of old technology units will be created. For various reasons, some owners of old technology units may not want to purchase of a new technology unit. On the other hand, some potential buyers of new technology units may purchase an old technology unit in order to benefit from the subsidy.
In fact, in this case the benefit from the subsidy will be reduced by the amount that will be paid to the initial owner. Call α' the effective amount of subsidy which these potential buyers will enjoy, i.e.
$\alpha' = \alpha$ - value of acquisition of an old technology unit
Typically, dealers will intervene in this secondary market and the effective subsidy level α' will become standardized.

An additional demand will be generated due to the second hand market. Call $q'_{0i}(.)$ the demand curve of the i th model.
Hence the introduction of a subsidy, will reduce the number of old technology units by:

$$Q_0(N_0,\alpha,\alpha') = \sum_{i=1}^{\kappa} q_{0,i}(p_i-\alpha) + \sum_{i=1}^{\kappa} q'_{0,i}(p_i-\alpha')$$

Note that Q_0 also depends also on the different model prices p_i, that are considered to be constants. It also depends on the demand curves
$q_{0,i}$ and $q'_{0,i}$ that are affected by a number of factors as well as N_0.

The group of owners of old technology units will, therefore decrease.
Let N_t be the size of this group at time t.

The corresponding demand curve, at time t, for model i, with respect to owners of old technology units, will be $q_{t,i}(.)$. Similarly $q'_{t,i}(.)$ refers to the demand generated through the second hand market. The decrease of old technology units observed at time t will be:

$$Q_t(N_t,\alpha,\alpha') = \sum_{i=1}^{\kappa} q_{t,i}(p_i-\alpha) + \sum_{i=1}^{\kappa} q'_{t,i}(p_i-\alpha')$$

which is the number of units withdrawn at time t.

Therefore, total withdrawals from time 0 until time t, is given by:

$$\int_0^t Q_s(N_s;\alpha;\alpha')\,ds$$

It is clear that:

$N_t = N_0$ - Total withdrawals

and, thus,

$$N_t = N_0 - \int_0^t Q_s(N_s;\alpha;\alpha')\,ds \qquad (1)$$

Next, we establish the limit constraints of the problem.

Call T the required time to replace L existing old technology units. By definition, the number of old technology owners, at time T, is $N_T=N_0 - L$.

In view of (1) this relationship yields:

$$N_T = N_0 - \int_0^T Q_s(N_s;\alpha;\alpha')\,ds = N_0 - L$$

which implies:

$$L = \int_0^T Q_s(N_s;\alpha;\alpha')\,ds \qquad (2)$$

Let p stand for the highest price of new technology models, i.e.

$p = \max \{ p_i: 1\leq i\leq k\}$

Suppose that, at time t, the subsidy is equal to p.

This implies that the government will fully subsidize the purchase of the most expensive model.

Assume that the subsidy benefit α', through the secondary market, also, equals p. This means that the owners of the old technology owners may:

- either purchase a new technology unit and withdraw the old one
- or sell at zero price their old technology unit to a potential buyer of a new technology unit, who will fully exploit the *generous* government subsidy.

In such a case, the secondary market will be eliminated and all old technology owners will choose to purchase the most expensive model. Therefore, all the old units will be immediately withdrawn, which leads to:

$$Q_t(N_t,p,p) = N_t \qquad (3)$$

Relationships (1), (2) and (3) describe our model.

4. An application

Assume that there is only one new technology model sold at price p.
A subsidy α is introduced. The corresponding benefit through the secondary market will be α'.
Let N_t be the number of old technology units at time t.
The demand curve at time t is considered to be linear:

$$q_t\,(\text{price}) = m \cdot \text{price} + b_t$$

Similarly, the demand through the secondary market will be:

$$q'_t\,(\text{price}) = m' \cdot \text{price} + b'_t$$

Note that the slopes remain constant while intercepts vary with time.

Withdrawals at time t, will be:

$$\begin{aligned} Q_t(N_t, \alpha, \alpha') &= m\,(p-\alpha) + b_t + m'\,(p-\alpha') + b'_t = \\ &= m\,(p-\alpha) + m'\,(p-\alpha') + (b_t + b'_t) \end{aligned} \qquad (4)$$

As there is only one model, relationship (3) can be written:

$$Q_t(N_t,p,p) = N_t$$

Substituting in relationship (4),

$$\begin{aligned} Q_t(N_t,p,0) &= m\,(p-p) + m'\,(p-p) + (b_t + b'_t) = \\ &= b_t + b'_t = N_t \end{aligned}$$

Hence, relationship (4) becomes:

$$Q_t(N_t, \alpha, \alpha') = m\,(p-\alpha) + m'\,(p-\alpha') + N_t$$

Relationship (1), can, now, be written as:

$$\begin{aligned} N_t = N_0 - \int_0^t Q_s(N_s;\alpha;\alpha')\,ds &= \\ = N_0 - \int_0^t (m(p-\alpha)+m'(p-\alpha')+N_s)\,ds &= \\ = N_0 - \int_0^t (m(p-\alpha)+m'(p-\alpha'))\,ds - \int_0^t N_s\,ds & \\ = N_0 - \{m\,(p-\alpha) + m'\,(p-\alpha')\}\,t - \int_0^t N_s\,ds & \end{aligned}$$

Let us call:

$$A = -m\,(p-\alpha) - m'\,(p-\alpha')$$

$$B = N_0$$

and $n(t) = \int_0^t N_s\,ds$

These relationships yield a first order differential equation:

$$\frac{dn(t)}{dt} = A \cdot t + B - n(t)$$

Solving,

$$e^t \frac{dn(t)}{dt} + e^t n(t) = A\, t\, e^t + B\, e^t$$

$$\frac{d(e^t n(t))}{dt} = A\, t\, e^t + B\, e^t$$

Hence,

$e^t n(t) = A\, t\, e^t - A\, e^t + B\, e^t + C$, where C is a constant.

It follows that:

$$n(t) = A\, t - A + B + C\, e^{-t}$$

which implies that:

$$N_t = \frac{dn(t)}{dt} = A - C\, e^{-t}$$

Note that, $N_0 = A - C$. Therefore, constant C can be determined $C = A - N_0$.

Substitution provides:

$$N_t = A + (N_0 - A)\, e^{-t} \qquad (5)$$

It is interesting to note that (5) can be written in the form:

$$N_t = (N_0 - Q_0) + Q_0\, e^{-t}$$

Let us, now, return to the two fundamental questions:

(a) Given a subsidy level α and a corresponding benefit α' (through the secondary market), determine the required time T to withdraw L old technology units.

Relationship (2), $N_T = N_0 - L$, in combination with (5) implies that:

$$N_T = A + (N_0 - A)\, e^{-T} = N_0 - L$$

Solving for T we get: $T = \log\left(\frac{N_0 - A}{N_0 - L - A}\right)$

Recall that $A = -\, m\,(p-\alpha) - m'\,(p-\alpha')$.

Substitution yields:

$$T = \log\left\{\frac{N_0 + m\,(p-\alpha) + m'(p-\alpha')}{N_0 - L + m(p-\alpha) + m'(p-\alpha')}\right\} \qquad (6)$$

Note that the above equation can be expressed as:

$$T = \log\left(\frac{Q_0}{Q_0 - L}\right) \qquad (7)$$

(b) For a given time period T, within which L old technology units will be withdrawn, determine the required subsidy level α.

Assume that the secondary market benefit α' is a fixed fraction of the subsidy level, i.e. $\alpha' = \delta \cdot \alpha$, where δ is a constant between 0 and 1.

Similarly as in (a),

$$A + (N_0 - A)\, e^{-T} = N_0 - L$$

Solving for A we have:

$$A = N_0 - \frac{L}{1 - e^{-T}}$$

Since $A = - m\,(p-\alpha) - m'\,(p-\alpha') = (m + m'\,\delta)\,\alpha - (m+m')p$,

$$(m + m'\,\delta)\,\alpha - (m+m')p = N_0 - \frac{L}{1 - e^{-T}}$$

which implies that:

$$\alpha = \frac{1}{m+m'\delta}\left\{ (m+m')p + N_0 - \frac{L}{1 - e^{-T}} \right\} \qquad (8)$$

5. Qualifications and concluding remarks

In the absence of a secondary market, $m' = 0$, the required subsidy level, as determined in (8), will be:

$$\alpha = p + \frac{N_0}{m} - \frac{L}{m(1 - e^{-T})}$$

The subsidy will be equal to the price of a new technology unit reduced by the amount: $\frac{1}{|m|}\left(N_0 - \frac{L}{1 - e^{-T}}\right)$.

Furthermore, if time T is infinite, the subsidy will get the smallest possible value: $\alpha = p + \frac{N_0 - L}{m}$, and if $N_0 = L$, then $\alpha = p$, as expected.

If time T is very small (approaches 0) then L tends to 0.

Based on (7), it is easily observed that, *ceteris paribus*, when the initial demand Q_0 is strong, the required time T is short. Similarly, the larger the number of withdrawals L, the longer the required time T to accomplish the objective.

A generalization is worth noting. The assumption of a linear demand curve can be easily relaxed without significant impact on the results. In particular, a demand relationship of any form, would lead to equation (7), provided that the intercept is the only time dependent term.

Finally the results should be interpreted as describing expected values. In empirical studies, deviations may be observed due to the stochastic nature of the involved variables.