

**Optimal Agricultural Land Pricing Policies under Multiple Externalities in a
Global Economy**

by

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Abstract

Agriculture has recently been noted as a provider of non-market environmental benefits in addition to its traditional recognition as a source of negative externalities from polluting inputs. In this paper, a general equilibrium framework is used to determine optimal land subsidies and input taxes in agriculture. When agriculture generates both amenities and pollution, the optimal subsidy does not equal the net extra-market value of agricultural land. If opened to international trade, a small economy will fully correct externalities, while large economies have an incentive to set policies at non-internalizing levels to exploit terms-of-trade effects.

Optimal Agricultural Land Pricing Policies under Multiple Externalities in a Global Economy

Although long recognized as a source of negative externalities, agricultural production has more recently been noted as a provider of non-market environmental benefits as well (Bergstrom; Crosson). Residents on the suburban fringes of major cities value nearby undeveloped spaces, tourists appreciate the agricultural landscape, and an increasingly urbanized citizenry values the existence of a rural way of life. Contingent valuation studies undertaken in several regions around the world have verified that such non-market values exist and are often substantial (Lopez, Shah, and Altobello; Hackl and Pruckner). Not surprisingly, recent political discussions have reflected a heightened interest in land use and the preservation of open spaces, even at the national level of government (e.g., Office of Management and Budget).

Accordingly, policy analysts have begun to explore the policies that can internalize the non-market benefits of agricultural land. Standard remedies such as taxes, subsidies, land use controls, and transferable development permits have been studied (Lopez, Altobello and Shah; Lopez, Shah and Altobello), and in some cases have already been implemented. Though it has been tacitly recognized that agricultural land is associated with other externalities such as pollution from chemical inputs, policies aimed at each problem have been “compartmentalized” and are typically analyzed independently (Poe).

Land use policy is often based on “net” amenities from agricultural land, and does not depend on other production regulations. Such policies ignore the interactions between policies; a tax or costly regulation on a polluting input necessarily reduces returns and raises the subsidy necessary to keep land in agriculture, while a subsidy on abatement activities would reduce the land use subsidy. Further, the size of the overall pollution externality depends on the number of

acres farmed, and changes in land use policy thus imply a change in the optimal pollution policy. In general, a change in social value of either externality implies an adjustment in both policies.

Environmental externalities are inevitably intertwined with international trade. In land-scarce regions such as Japan, Korea, and Switzerland, protection of domestic agriculture has historically retarded the flow of land into other uses. On the other hand, the effect of environmental policies on trade flows has been the subject of heated political discussions and trade negotiations. For the case of a single externality, various policies have been widely studied and their relationships to trade are now theoretically well understood (Anderson; Copeland; Krutilla; Schamel and de Gorter). However, these policies have never been studied in the more realistic case of multiple, related externalities.

This paper examines optimal policies to correct multiple externalities in a general equilibrium setting. The first section describes a model economy comprised of two sectors, where the agricultural sector generates both non-market benefits (land amenities) and costs (pollution). Assuming the economy is closed to international trade, welfare-maximizing policies are then derived, and the relationship between the policies is analyzed. The second section determines optimal domestic policies under free trade. Domestic welfare-maximizing factor allocations are derived for both the small and large country cases, and are compared to the allocations that maximize global welfare. The third section provides some conclusions and policy implications.

The Model Economy

Consider an economy comprised of a large number of identical individuals who consume two commodities: agricultural goods, denoted a , and non-agricultural or “manufactured” goods,

m. The two commodities are produced according to the production functions $F_a(L_a, X_a)$ and $F_m(L_m, X_m)$, where L_i and X_i are the amount of land and other inputs allocated to the production of good i , respectively. Consumers are collectively endowed with L acres of land and X units of other inputs, and the entire endowment of each factor is homogeneous in quality. Each $F_i(\cdot)$ is strictly increasing, strictly concave, and exhibits constant returns to scale. By homogeneity, $F_i(L_i, X_i) = L_i F_i(1, X_i/L_i) \equiv L_i f_i(x_i)$, where x_i represents the X_i/L_i ratio (per-acre input) and $f_i(\cdot)$ is the per-acre production function.

Agricultural production leads to two externalities. First, consumers receive amenity and “open space” benefits from land allocated to agriculture. Second, the use of other input in agriculture X_a generates pollution. Because the total amount of emissions E also depends on the number of acres farmed, the pollution function G depends on L_a : $E = G(L_a, X_a)$. If L_a and X_a both double (thus keeping x_a constant), total emissions also double when land is of undifferentiated quality. Hence, $G(\cdot)$ is homogeneous of degree one. By the same argument as above, emissions may be equivalently expressed as $E = L_a g(x_a)$, where $g(\cdot)$ represents the amount of pollution generated per acre. Assume that g is strictly increasing, weakly convex, and that $g(0) = 0$.

Consumers’ preferences are represented by the aggregate utility function $u(a, m, L_a, E)$, where $u(\cdot)$ is strictly quasi-concave, strictly increasing in a , m , and L_a , and strictly decreasing in E . National income I is the total payments received on the factors used in the two industries. Consumers use income to purchase a and m , but cannot influence the levels of L_a and E . Taking m to be the numeraire and letting p be the price of a , indirect utility is:

$$\begin{aligned} v(p, I, L_a, E) &= \max_{a, m} u(a, m, L_a, E) \\ \text{s.t.} \quad & pa + m \leq I, \quad (a, m) \in \mathfrak{R}_+^2 \end{aligned}$$

The function $v(\cdot)$ can be interpreted as social welfare for a given combination of price, income, agricultural land allocation, and pollution. The solutions to the maximization problem $a(p, I, \cdot)$ and $m(p, I, \cdot)$ are the demands for agricultural and manufactured goods, respectively.

If the utility function is properly restricted so that $a(\cdot)$ and $m(\cdot)$ are monotonic in p , there is a unique price that will clear the markets for any amount of agricultural production. Further, given that technologies satisfy constant returns to scale, factor payments from each industry are equal to revenues. Therefore, p and I can be regarded as functions of L_a and x_a , and these relationships are implicitly defined by the equations:

$$(1) \quad a(p(L_a, x_a), I(L_a, x_a), \cdot) = L_a f_a(x_a)$$

$$(2) \quad I(L_a, x_a) = p(L_a, x_a)L_a f_a(x_a) + (L - L_a)f_m(x_m)$$

where $x_m = (xL - x_a L_a)/(L - L_a)$, and $x \equiv X/L$. The problem of maximizing social welfare in a closed economy is:

$$(3) \quad \max \quad v(p(L_a, x_a), I(L_a, x_a), L_a, L_a g(x_a))$$

$$L_a \in [0, L], \quad x_a \in [0, xL/L_a]$$

If $p(\cdot)$, $I(\cdot)$, and $g(\cdot)$ are continuous, a solution must exist on the compact set $[0, L] \times [0, xL/L_a]$.

Let (L_a^0, x_a^0) represent the solution to (3). Under appropriate assumptions on $u(\cdot)$ and $F_i(\cdot)$, this solution cannot occur on the boundary of the constraint set,¹ and must therefore satisfy the first-order conditions:

$$(4) \quad v_p p_L + v_I I_L + v_L + v_E g(x_a) = 0$$

$$(5) \quad v_p p_x + v_I I_x + v_E L_a g'(x_a) = 0$$

¹ More precisely, if marginal utilities and marginal products become infinite as their respective arguments approach zero then there must be a positive allocation of both factors to both industries.

where subscripts denote derivatives. The Envelope Theorem implies that $v_I = u_m$, $v_L = u_L$, and $v_E = u_E$; $v_p = -a(p, I)v_I$ by Roy's Identity; and the first order conditions for utility maximization require that $p = u_a/u_m$. Substituting these conditions, the derivatives of I from (2), and the market clearing condition (1) into (4) and (5), one obtains the following equivalent conditions expressed in terms of the utility and production functions:

$$(6) \quad \frac{u_a}{u_m} f_a(x_a) - [f_m(x_m) - f'_m(x_m)(x_m - x_a)] + \frac{u_L}{u_m} + \frac{u_E}{u_m} g(x_a) = 0$$

$$(7) \quad \frac{u_a}{u_m} f'_a(x_a) - f'_m(x_m) + \frac{u_E}{u_m} g'(x_a) = 0$$

Each of these conditions requires that the net marginal benefits of each variable be zero.

Equation (6) defines the optimal allocation of L_a . the first term is the marginal benefit of using land to produce a , the term in brackets is the marginal opportunity value of using land to produce m , u_L/u_m is the amenity benefit of land in agriculture, and the last term (note that $u_E < 0$) is the marginal cost of pollution. Because each term has been divided by u_m , the benefits and costs are compared in terms of the numeraire. In equation (7), the optimal choice of x_a is determined by setting to zero the sum of the marginal benefits of producing a , the marginal opportunity value in terms of m production foregone, and marginal environmental cost. Even though each of the preceding equations describes the optimal allocation of one factor, they are collectively a simultaneous system in both variables (L_a appears in both equations through the expression for x_m). Any shift in preferences that changes either u_L or u_E therefore implies a change in both L_a^0 and x_a^0 .

Because L_a and E are public goods, the market price system cannot internalize the marginal amenity benefits of agricultural land and the marginal cost of pollution, and producers will not choose the socially optimal factor allocation unless there is some policy intervention.

The policy problem is therefore to determine a subsidy on agricultural land (s) and a tax on agricultural input (t) that allow the socially optimal outcome to be decentralized through free markets. Given a price p , a set of policies (s, t) , and factor endowments (L, X) , the behavior of domestic producers can be described by the revenue function:

$$R(p, s, t, L, X) = \max pL_a f_a(x_a) + sL_a - tL_a x_a + (L - L_a) f_m(x_m)$$

$$L_a \in [0, L], \quad x_a \in [0, X/L_a]$$

Because the maximand is strictly concave, the unique solution must satisfy the first order conditions:

$$(8) \quad p f_a(x_a) + s - t x_a - [f_m(x_m) + f_m'(x_m)(x_m - x_a)] = 0$$

$$(9) \quad p f_a'(x_a) - t - f_m'(x_m) = 0$$

Using the fact that $u_a/u_m = p$ and comparing (6) and (7) to (8) and (9), the welfare-maximizing choices of s and t must satisfy:

$$(10) \quad s - t x_a^o = \frac{u_L}{u_m} + \frac{u_E}{u_m} g(x_a^o)$$

$$(11) \quad t = -\frac{u_E}{u_m} g'(x_a^o)$$

where the derivatives of $u(\cdot)$ are evaluated at the socially optimal levels L_a^o and x_a^o . In words, equation (11) states that the optimal tax is the marginal social cost of applying agricultural inputs at x_a^o . A rearrangement of (10) implies that the optimal subsidy is made up of three components. First, firms employing an acre of land in agriculture must be rewarded for the amenity benefit u_L/u_m . Second, agricultural land use is penalized by the cost of the pollution generated per acre, $u_E/u_m g(x_a^o)$. Finally, the farmers must also be compensated for the cost imposed by the pollution tax, $t x_a^o$.

The compensation component in the subsidy is necessary to make the private and social allocation conditions coincide. By equation (8), private firms consider the tax expense in the decision to employ agricultural land, but an analogous term is not present in the socially optimal condition (6). Therefore, a land use subsidy equal to the “net” value of amenities per acre $[u_L/u_m + (u_E/u_m)g(x_a^o)]$ will not achieve an efficient allocation of land, unless farmers are separately compensated for the cost of the input tax.

Consider now the special cases single externalities. If there is no pollution externality (either $u_E \equiv 0$ or $g(x_a) \equiv 0$), then $t = 0$ and $s = u_L/u_m$; farmers are rewarded for exactly the external benefit of agricultural land. If there are no land amenities (i.e., $u_L \equiv 0$), the tax is given by equation (11). Substituting the expression for the tax into (10), the optimal subsidy is:

$$s = \frac{u_E}{u_m} [g(x_a^o) - g'(x_a^o)x_a^o]$$

If $g'' \geq 0$ and $g(0) = 0$, the expression in brackets is nonpositive. Combined with the fact that $u_E < 0$, this implies that $s \geq 0$. Even when agricultural land generates no amenity value, it is optimal to subsidize agricultural land. Only in the special case $g'' = 0$ would a land subsidy be unnecessary.

If both u_E and u_L are positive, the optimal levels of s and t are based on the welfare maximizing allocations L_a^o and x_a^o , which are in turn determined in a simultaneous system (equations (6) and (7)). Consequently, any change in the value of either externality (i.e., a shift in u_L/u_m or u_E/u_m) would induce an adjustment in both the optimal allocation (L_a^o, x_a^o) and policy choice (s, t) . For example, suppose the value of agricultural land amenities increases by \$ b per acre. In general, this change would lead to some (nonzero) adjustment in the optimal input tax

even if u_E/u_m remains fixed, and the optimal land subsidy would change by some amount other than \$b.

Open Economies

Suppose the economy described above is opened to international trade with another “foreign” region. For simplicity, assume that foreign and domestic production technologies are identical, and that foreign agriculture does not generate any externalities. The allocations that maximize global welfare can be determined by solving the combined Pareto problem:

$$\begin{aligned} \max \quad & u(a, m, L_a, L_a g(x_a)) + \alpha u^*(a^*, m^*) \\ \text{subject to:} \quad & a + a^* = L_a f_a(x_a) + L_a^* f_a(x_a^*) \\ & m + m^* = (L - L_a) f_m(x_m) + (L^* - L_a^*) f_m(x_m^*) \\ & L_a \in [0, L], x_a \in [0, xL/L_a], L_a^* \in [0, L^*], x_a^* \in [0, x^* L^* / L_a^*] \end{aligned}$$

where α is the relative welfare weight of foreign consumers, and asterisks denote foreign variables. The first-order necessary conditions for allocations of land and input (assuming an interior solution) simplify to:

$$(12a) \quad u_a f_a(x_a) - u_m [f_m(x_m) - f_m'(x_m)(x_m - x_a)] + u_L + u_E g'(x_a) = 0$$

$$(12b) \quad u_a f_a'(x_a) - u_m f_m'(x_m) + u_E g'(x_a) = 0$$

$$(12c) \quad u_a^* f_a(x_a^*) - u_m^* [f_m(x_m^*) - f_m'(x_m^*)(x_m^* - x_a^*)] = 0$$

$$(12d) \quad u_a^* f_a'(x_a^*) - u_m^* f_m'(x_m^*) = 0$$

Equations (12a) and (12b) describe the optimal levels of L_a and x_a , respectively, while (12c) and (12d) correspond to the optimal allocations in the foreign economy. In the foreign country, each factor is employed in agriculture until the marginal benefits of agricultural production equal the

opportunity value of manufactured production. The domestic allocation equations include terms for the externalities, and are identical to the closed economy conditions in equations (6) and (7).

Though a global perspective is of theoretical interest, it is reasonable to assume that the home government wishes only to maximize domestic welfare. The remainder of this section determines the allocations that are optimal from this domestic viewpoint, and compares each outcome with those that maximize global welfare. The small country and large country cases are analyzed in turn.

A small open economy views the world price of agricultural goods as an exogenous variable. Letting p represent this price, national income is:

$$I(L_a, x_a) = pL_a f_a(x_a) + (L - L_a) f_m(x_m)$$

The social welfare maximization problem becomes:

$$\max \quad v(p, I(L_a, x_a), L_a, L_a g(x_a))$$

$$L_a \in [0, L], x_a \in [0, xL/L_a]$$

with first order conditions:

$$v_I I_L + v_L + v_E g(x_a) = 0 \quad \text{and} \quad v_I I_x + v_E L_a g'(x_a) = 0$$

Substituting the derivatives of I from the definition above and the envelope conditions $v_I = u_m$,

$v_L = u_L$, and $v_E = u_E$, these conditions reduce to:

$$p f_a(x_a) - [f_m(x_m) - f'_m(x_m)(x_m - x_a)] + \frac{u_L}{u_m} + \frac{u_E}{u_m} g(x_a) = 0$$

$$p f'_a(x_a) - f'_m(x_m) + \frac{u_E}{u_m} g'(x_a) = 0$$

Because $p = u_a/u_m$, these conditions imply exactly the same factor allocation that maximizes world welfare in conditions (12a) and (12b). Therefore, the optimal domestic policy for a small open economy is also optimal from a global point of view.

If the home economy is large enough so that changes in domestic production and consumption affect the world price, the price must be regarded as endogenous. The policy problem becomes:

$$\begin{aligned} \max \quad & v(p(L_a, x_a), I(L_a, x_a), L_a, L_a g(x_a)) \\ & L_a \in [0, L], x_a \in [0, xL/L_a] \end{aligned}$$

The price and income relations $p(\cdot)$ and $I(\cdot)$ satisfy:

$$(13) \quad a(p, I, \cdot) = L_a f_a(x_a) + a^*(p)$$

$$(14) \quad I = pL_a f_a(x_a) + (L - L_a) f_m(x_m)$$

where the arguments of p and I have been suppressed to simplify notation, and $a^*(\cdot)$ is the foreign excess supply function. The first order conditions are:

$$v_p p_L + v_I I_L + v_L + v_E g(x_a) = 0 \quad \text{and} \quad v_p p_x + v_I I_x + v_E L_a g'(x_a) = 0$$

Substituting the derivatives of v ($v_I = u_m$, $v_L = u_L$, $v_E = u_E$) and I , the condition $p = u_a/u_m$, Roy's

Identity $v_p = -av_I$, and market clearing, these conditions become:

$$(15) \quad \frac{u_a}{u_m} f_a(x_a) - a^*(p) p_L - [f_m(x_m) - f'_m(x_m)(x_m - x_a)] + \frac{u_L}{u_m} + \frac{u_E}{u_m} g(x_a) = 0$$

$$(16) \quad \frac{u_a}{u_m} f'_a(x_a) - a^*(p) p_x - f'_m(x_m) + \frac{u_E}{u_m} g'(x_a) = 0$$

Compared to those that maximize world welfare (equations (12a) and (12b)), each of these conditions contains the extra term $-a^*(\cdot)p_j$, or the product of exports and the change in price with respect to factor j . Assuming that $a_p < 0$ and $a_p^* > 0$, the derivatives of the market clearing condition (13) with respect to L_a and x_a imply that $p_L < 0$ and $p_x < 0$. Thus, a domestic planner could decrease the world price by increasing either of the factor allocations to agriculture. If the domestic economy is an agricultural importer, then $a^* > 0$ and the extra terms in each condition are positive. This implies that the marginal benefits of L_a and x_a are higher vis-à-vis the small

economy case, and the optimal allocations are higher as well. If the home economy is an exporter ($a^* < 0$), the extra terms are negative, implying a smaller allocation of factors to agriculture.

These results are intuitively consistent with the use of subsidies and taxes to regulate a single externality (Krutilla); importers gain from policies that decrease the world price, and the reverse is true for exporters. If policy interventions must be justified on the basis external benefits and costs, the model predicts that importers' policies will emphasize the benefits of agricultural land and undervalue the environmental costs of agricultural inputs, while exporters are likely to do the opposite.

Policy Implications

This paper has determined the optimal policy rules when agricultural production generates both landscape amenities and pollution from chemical inputs. The optimal subsidy on land and tax on non-land inputs depend on the size of both externalities; a change in the social value of either land amenities or pollution implies a change in both policies. Further, the optimal land subsidy does not equal the net value of land amenities. The estimates of non-market land benefits in empirical studies therefore cannot be interpreted as the appropriate subsidy on agricultural land.

As a practical matter, the external benefits and costs of agricultural land vary by location, and the relationship between inputs and pollution is generally unknown. Consequently, regulators achieve environmental goals by enforcing standards on input use. Even though land use and agricultural pollution are regulated by different agencies and are often treated as separate issues, the respective policies should not be chosen independently. Agricultural land use

depends on whether farmers are compensated for the cost of other regulations, and the appropriate chemical standards depend on the number of acres farmed.

If opened to international trade, small economies will choose the same policies that maximize world welfare, but large economies have an incentive to set policies at non-internalizing levels to exploit terms of trade effects. In particular, large importers will choose policies that increase agricultural factors beyond globally efficient allocations, while large exporters prefer to restrict factor allocations (and hence agricultural production) to raise the international price. For large economies, production policies that are ostensibly justified on environmental grounds can become instruments to distort international prices.

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