Achieving Environmental Objectives Under Reduced Domestic Agricultural Support and Trade Liberalization: An Empirical Application to Taiwan

Hung-Hao Chang, Richard N. Boisvert, and David Blandford

We focus on rice policy reform required for Taiwan's admission to the WTO, and examine the effects, theoretically and empirically, of the re-instrumentation of domestic policy needed to achieve environmental objectives when both positive and negative environmental externalities exist. Policies that treat non-commodity attributes in agriculture as secondary to existing aims, such as income support, are unlikely to result in the desired supplies of environmental goods. Those supplies can be achieved at lower government and social costs using policy instruments to achieve environmental goals directly. Results are relatively insensitive to the social values assigned to environmental goods.

Key Words: WTO policy reform, multifunctionality, agri-environmental policy, rice policy, agricultural trade policy

Prior to the signing of the Uruguay Round agreement in 1994 and the subsequent creation of the World Trade Organization (WTO), agricultural policies in industrial countries were largely oriented towards income support. Since the mid-1990s, the policy debate has been increasingly dominated by a range of other issues, including the impact of agriculture on the environment. This shift in policy focus is reflected in the concept of "multifunctionality"—i.e., agriculture as a source of multiple outputs that extend beyond crop and livestock products into less tangible attributes such as environmental quality, landscape, and cultural heritage. In many countries, agricultural policies are being re-evaluated from the perspective of their impact on the supply of both commodity and non-commodity attributes. This re-examination raises important questions about the extent to which domestic policy objectives can be achieved under current disciplines on international agricultural trade.

It has been common to view the supply of environmental attributes as a secondary factor in the pursuit of traditional policy objectives, such as income support, and to focus policy evaluation on a single environmental attribute. We have argued elsewhere that an approach that treats environmental aims as subsidiary factors is an outdated policy paradigm (Blandford and Boisvert 2002). To address new concerns, such as how food is produced and environmental issues, a new paradigm is needed in which policy instruments are oriented towards achieving the appropriate supply of both non-commodity and commodity attributes of agriculture. It is also important that such a paradigm be consistent with the liberalization of international trade.

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An earlier version of this paper was presented at the International Trade and the Environment Workshop sponsored by the Northeastern Agricultural and Resource Economics Association and the U.S. Environmental Protection Agency, National Center for Environmental Economics, in Halifax, Nova Scotia, on June 23, 2004.

We wish to thank the Council of Agriculture, Taiwan, the Asian Rice Foundation, and the Department of Applied Economics and Management at Cornell University for financial support, and for the assistance of the Agricultural Engineering Research Center (AERC) in collecting data on rice production and the non-market values for important non-commodity outputs. We also thank James S. Shortle for helpful comments on an earlier draft of the paper. The comments from an anonymous reviewer were also helpful. The results and their interpretation are those of the authors' and are not necessarily those of the U.S. Environmental Protection Agency, the Council of Agriculture, or the AERC. The authors accept responsibility for any errors or omissions.

Agricultural and Resource Economics Review 34/1 (April 2005) 16–31

Objectives

This paper addresses the key elements of such a new policy paradigm and its implications by focusing on the reforms in Taiwan's rice policy required for the country's admission to the WTO. Through empirical simulations, we examine the re-instrumentation of domestic policy to achieve environmental objectives. We analyze policies that address both positive and negative environmental externalities, and we assess the implications of trade liberalization for optimal policy choice.

In the theoretical section below, we first review some key conceptual issues relevant to policy design. These include the relationship between agricultural production and the supply of non-commodity attributes. In this regard, we pay particular attention to the fact that both commodity and non-commodity outputs are produced jointly but not in fixed proportions. We also underscore important conceptual issues in the valuation of non-commodity outputs that are jointly produced. In evaluating optimal policy choice, we give particular attention to instruments that are appropriate when it is difficult to observe and monitor the supply of environmental attributes associated with agricultural production. Optimal levels of policy instruments are shown to depend on the extent to which there are distortions in domestic markets caused by either domestic or trade policy measures.

We focus on rice policy in Taiwan to illustrate the practical significance of these issues for domestic policy reform and trade liberalization. Prior to joining the WTO in January 2002, Taiwan operated an autarkic rice policy in which imports were prohibited. A price support program was in place, combined with a land set-aside to control supply. As a result of its membership in the WTO, a tariff rate quota (TRQ) was introduced to permit limited imports of rice. Imports are made through a state trading enterprise (STE), which controls their release onto the domestic market. The price support/set-aside program continues to be used. Given that a degree of trade liberalization has recently occurred, we are able to explore the implications of a shift in domestic policy from price support to one in which environmental objectives are paramount under conditions of autarky, and when the economy is opened to limited international competition.

A primary objective of this paper is to identify the environmental policies that will lead to socially optimal levels of both groundwater recharge (a positive externality) and methane gas (a negative externality) generated by paddy rice production. Both of these environmental externalities have figured prominently in the debate on the environmental impact of rice production in Taiwan and other Asian countries and the potential impact of reforms in domestic and international agricultural policies (Yang 2000; Lin, Pon, and Hsu 2002; Tsai 1993; Asian Productivity Organization 2001). Because of the wide range in estimates of the social value of these two externalities in the literature, we focus our sensitivity analysis of the empirical results on the range in estimates of these environmental values.

Theoretical Model

To set the stage for the theoretical development of optimal policies for the provision of multifunctional outputs, it is essential to specify a transformation function (production possibility frontier) for the rice sector. Assuming there are fixed resource endowments of two inputs (L, Z), the transformation frontier for both rice production (q) and two non-commodity environmental outputs (E_1 and E_2) can be represented as

$$(1) \qquad T(q, E_1, E_2; L, Z) = 0 .$$

In addition to its regularity properties, two key characteristics are required for this transformation relation to represent multifunctional agriculture. First, the commodity and non-commodity outputs must be produced jointly, and second, the non-commodity outputs must have a "public" good nature; they are non-market goods that are non-rival in consumption.[1] As Boisvert (2001a, 2001b) suggests, there are three conditions that lead to jointness in production, but in the multifunctional case, it is perhaps easiest to think of the joint production where non-allocable inputs are used in the production of multiple outputs—that is, where the outputs are obtained from one and the same input.[2] In that case, production is joint in inputs,

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[1] In the empirical application below, the two jointly produced non-commodity outputs, E_1 and E_2, are positive and negative environmental externalities, respectively. Thus, throughout the paper, the terms non-commodity outputs, multifunctional outputs, and environmental externalities are used interchangeably.

[2] The case of non-allocable factors could also be discussed within the context of technical interdependencies. In fact, "jointness in inputs," which is given when an input simultaneously contributes to the produc-

and one cannot disentangle the separate contribution of each input to each product. Thus, total input use is not determined by summing inputs used by each product; this would result in double counting.[3]

Both of these characteristics have important implications for modeling farm-level and market behavior. For example, if we assume competitive markets and ignore the social value of non-commodity outputs, a farmer would maximize profits by equating the marginal value product of each input with its price. If it is possible to observe the levels of production of the non-commodity outputs, then we also know that to maximize social welfare, it is sufficient to tax (subsidize) the negative (positive) public good (or externality) at its marginal social cost (value) (Baumol and Oates 1988). These Pigouvian taxes (subsidies) modify the first-order conditions for the farmer's profit maximization.

Although the logic of the Pigouvian principle is particularly compelling at a theoretical level, its practical application is less straightforward. In this theoretical section, we anticipate a couple of difficulties in adapting the theory specifically for our empirical application to rice in Taiwan. As is seen below, the first difficulty stems from the fact that the levels of the externalities (public goods) are difficult to observe and measure. Thus, it would be difficult, if not impossible, to apply the Pigouvian principle directly. Further, as in most wealthy countries, there are market distortions in the form of domestic agricultural policy intervention to protect producers' income, and/or barriers to international trade. Baumol and Oates (1988) were among the first to show that, under these conditions, the Pigouvian taxes (subsidies) would have to be set at levels different from their marginal social costs (benefits).[4] Although there are currently efforts in Taiwan to reduce the level of domestic support and expand international trade, market distortions have not been eliminated completely. Thus, it is important to determine what levels of policy instruments ensure the socially optimal supply of non-commodity outputs in the presence of these distortions.

The issue of non-observability of the non-commodity externalities is addressed by targeting multifunctional policy intervention at observable variables that are correlated with the externality-generating process (Rude 2001, Romstad 1999), such as the inputs used for agricultural production. Indeed, in the absence of market distortions, the first-best welfare scenario can still be achieved if the appropriate taxes (subsidies) are applied to *all* inputs contributing to the production of the non-commodity externalities or "public" goods (Holtermann 1976, Griffin and Bromley 1982).[5] Peterson, Boisvert, and de Gorter (2002) demonstrate this principle in the case where both positive and negative non-commodity externalities are jointly produced with agricultural commodity outputs. In this paper, we extend that type of analysis to the case where there are also market distortions. The appropriate modifications in the levels of the input taxes (subsidies), for

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tion of several commodities, can be considered one of the reasons for technical interdependence. See Shumway, Pope, and Nash (1984) and Leathers (1991) for rigorous mathematical definitions of jointness in production.

[3] The classical examples of joint products—production of mutton and wool obtained from sheep, and oil and meal from soybeans—fit this category nicely, as does the production of milk and landscape amenities by cows grazing on pasture or corn and nitrate leaching and runoff due to the application of commercial fertilizer. In the latter two cases, production of the commodity and non-commodity outputs is not in fixed proportions. Because we cannot separate the contributions of cows and pasture to the production of milk and amenities, production is joint. It is also impossible to disentangle the contribution of fertilizer to corn and to leaching runoff. If we count the pollution from animal waste, there is a third joint product in our dairying example. Landscape amenities from land in crops would add a third joint commodity to the corn production example, in that land's contribution to corn production cannot be disentangled from its contribution to amenities. In the empirical application below, the joint contribution of irrigation water to the production of paddy rice and groundwater recharge serves as another example. The same is true for the joint production of rice and methane.

[4] For example, to recognize that the level of a negative environmental externality under imperfect competition is already below its level under perfect competition, the socially optimal tax must be set at less than the marginal social damage (Lee 1975, Barnett 1980). Gopinath and Wu (1999) derive conditions under which the desire of producers of agricultural chemicals to under-produce because of market power would be exactly offset by their tendency to over-produce by ignoring the externality costs of agricultural chemicals. Lichtenberg and Zilberman (1986) also examine the welfare impacts of revenue support programs (e.g., price support, marketing orders, and import quotas) in agricultural product markets.

[5] Shortle, Horan, and Abler (1998, pp. 574–575) also argue that these instruments provide the correct marginal incentives for input use, but do not ensure that the set of firms left in the industry will be the efficient ones. Thus, they argue that an additional instrument, one that does not distort input levels, may be needed to influence entry and exit of firms. This could be in the form of a lump-sum tax on extra-marginal firms to ensure negative profits if they produce, or in the form of a subsidy for not producing that would be larger than their after-tax profits. Further, while no such tax would be required for marginal or infra-marginal firms, a lump-sum subsidy may be necessary for those firms whose entry or exit is influenced by the input taxes or subsidies. The necessity for this lump-sum tax or subsidy clearly has implications for the re-instrumentation of government policy where there remains a desire to support the incomes of agricultural producers.

what is now a second-best optimum due to the domestic and/or international policy intervention, are derived in a manner similar to that when the market distortion is in the form of imperfect competition.

To derive the optimal second-best multifunctional policy, we develop a two-stage approach around a partial equilibrium model of an agricultural market in which there are jointly produced non-commodity outputs. In the first stage, the government implements the optimal policy design by taxing or subsidizing land and other inputs (Peterson, Boisvert, and de Gorter 2002).[6] Given the levels of the policy instruments announced by the government, the representative rice farmer makes an optimal decision on the use of agricultural inputs in a second stage. Since this two-stage problem is solved through backward induction (Tirole 1988), it is convenient to begin with a discussion of the second stage.

Optimal Decisions of Producers, Given Domestic Support Policy

To understand the implications of domestic support for optimal multifunctional policy design, we must formulate the producer's decision problem within the context of the specific design of agricultural support policy for rice in Taiwan using a strategy similar to Fraser (2003) in modeling the effects of a reduction in domestic support for agriculture in Europe. In Taiwan, there is both a price support program (the limited purchase support program) and a land set-aside program, the "Rice Paddy Utilization Adjustment Program" (RPUAP) (Huang 2001). There is a payment for each hectare set aside, but the government also limits purchases of rice at the support price to a fixed quantity per hectare. This is an important feature of the policy because it is likely that the supply-inducing price at the margin will be the domestic market-clearing price, rather than the support price.

The representative rice farmer is assumed to maximize profit, where the farmer's revenue includes market sales of rice, rice sold to the government at the support price, and payments for the set-aside land area. The farmer's decision problem is

$$\text{(2)}\quad \underset{L,Z}{\text{Max}}\,\pi = p\left\{F(\alpha L, Z) - \alpha L\overline{Q}\right\} + \alpha L\overline{P}\overline{Q} + (1-\alpha)LP_s - P_l L - P_z Z + s(\alpha L) - tZ,$$

where $F(.)$ is the production function for rice, p is the equilibrium market price for rice, α is the mandatory proportion of total land, L, in rice production, $(1 - \alpha)$ is the proportion of land enrolled in the set-aside program, Z is the other input used in rice production, $\overline{P}$ is the per unit government purchase price, $\overline{Q}$ is the government purchase quantity of per hectare, P_s is the per hectare set-aside payment, P_l is the price of land, and P_z is the price of a purchased input. Assuming that land contributes to the production of the positive externality, E_1 from equation (1), and that Z contributes to the negative externality, E_2 from equation (1), s and t are the subsidy and tax, respectively, on inputs needed to ensure the appropriate production of the non-commodity environmental output variables. The levels of these policy instruments are determined in the first stage of the policy design problem described below. The first term in the profit function is market revenue; the second term is the revenue from government purchases based on maximum per hectare quantity $\overline{Q}$; the third term is the revenue from RPUAP; and the last two terms are the subsidy revenue and tax cost to the farmer associated with input use.

The first-order necessary conditions for an interior solution are

$$\text{(3)}\quad \frac{\partial\pi}{\partial L} = \alpha P\frac{\partial F}{\partial L} + \alpha\overline{Q}(\overline{P} - P) + (1-\alpha)P_s + \alpha s - P = 0$$

and

$$\text{(4)}\quad \frac{\partial\pi}{\partial Z} = P\frac{\partial F}{\partial Z} - P_z - t = 0\,.$$

The economic intuition behind equations (3) and (4) may be demonstrated by comparing the marginal cost and benefit of the use of each input. For optimal land use, equation (3), the first term is the marginal revenue from selling rice on the market; the second term is the marginal payment received through the price support program; the third term is the marginal payment for the land set aside; and the fourth term is the marginal subsidy for the contribution of land in production to the supply of a "positive" non-commodity environ-

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[6] For simplicity of exposition, only two inputs are considered in this conceptual analysis. The results extend in a straightforward fashion to the four inputs (fertilizer, labor, land, and water) included in the empirical model subsequently developed for paddy rice in Taiwan.

mental output. The solution of the farmer's optimization problem requires that these combined marginal (net) contributions of land to profit are equated to the price of land. Assuming that the marginal product of land is declining, and since the three terms involving policy instruments are positive, the optimal use of land will tend to be higher than under competitive market conditions in the absence of a price policy and an environmental policy that explicitly recognizes the social value of the positive non-commodity externality. In contrast, we can see from equation (4) that the optimal level of the purchased input will tend to be below what it would be in a competitive market because of the assumed effect of the use of the input on the output of the negative non-commodity externality (equation 4). The value of the marginal product of Z is equated to its price plus the tax on Z.

Optimal Environmental Policy Design

Given the solution to the rice farmer's profit-maximizing problem, second-best optimal environmental policies can be derived by maximizing the social welfare function. If social welfare is represented by the sum of consumers' and producers' surpluses, less governmental budget costs and the net value of the non-commodity environmental externalities, net social welfare can be expressed as

$$(5)\quad \begin{aligned} SW = {} & \int_0^{Q^c} p(h)dh - p(Q^c)Q + \pi(p, \overline{P}, \overline{Q}, P_s, t, s) \\ & + B\left(E_1(\alpha L, Z)\right) - D\left(E_2(\alpha L, Z)\right) \\ & - \alpha L\overline{Q}(\overline{P} - P) - (1-\alpha)LP_s + tZ - s(\alpha L), \end{aligned}$$

where $p(h)$ is the demand curve for rice, $P(Q^c)$ is the equilibrium price, and π is the farmer's indirect profit function. The function $B(.)$ is the total benefit function associated with the positive environmental externality, and the function $D(.)$ is the total damage function associated with the negative externality.[7]

Thus, the first two terms of equation (5) represent consumers' surplus; the third term is the profit of the representative rice farm; and the fourth and fifth terms are the benefit and damage functions associated with the positive and negative non-commodity externalities that are supplied jointly with a given level of inputs in rice production. The remaining two terms represent government taxes and subsidies, respectively, on the two agricultural inputs.

We apply Shephard's lemma to determine the optimal levels of the two new policy instruments by partially differentiating equation (5) with respect to t and s. The first-order necessary conditions for an interior solution to the maximization of social welfare are

$$(6)\quad \begin{aligned} \frac{\partial SW}{\partial t} = {} & \frac{\partial L}{\partial t}\{\alpha\, [B'\frac{\partial E_1}{\partial L} - D'\frac{\partial E_2}{\partial L} - s - (\overline{P} - P)\overline{Q}] \\ & -(1-\alpha)P_s\} \\ & + \frac{\partial Z}{\partial t}\{B'\frac{\partial E_1}{\partial Z} - D'\frac{\partial E_2}{\partial Z} + t\} = 0, \end{aligned}$$

and

$$(7)\quad \begin{aligned} \frac{\partial SW}{\partial s} = {} & \frac{\partial L}{\partial s}\{\alpha[B'\frac{\partial E_1}{\partial L} - D'\frac{\partial E_2}{\partial L} \\ & -s - (\overline{P} - P)\overline{Q}] - (1-\alpha)P_s\} \\ & + \frac{\partial Z}{\partial s}\{B'\frac{\partial E_1}{\partial Z} - D'\frac{\partial E_2}{\partial Z} + t\} = 0. \end{aligned}$$

Making the reasonable assumption that the partial derivatives of the input levels with respect to the tax and subsidy are non-zero, the levels of t and s

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[7] There are two issues that must be addressed in specifying these environmental benefit and cost functions. The first has to do with non-market valuation. As the list of non-trade concerns has expanded, there has been a recognition of the difficulties posed in estimating the non-market values for jointly produced non-commodity outputs of agriculture. It has been noted by Hoehn and Randall (1989) and Carson, Flores, and Hanemann (1998) that, regardless of whether the non-market values are estimated by indirect methods, such as averting behavior and hedonic price approaches, or by direct methods, such as contingent valuation, serious problems can arise if net social benefits are estimated by summing individual values of the separate non-market goods, each derived independently using conventional valuation procedures. Carson, Flores, and Hanemann (1998) motivate their work by noting one disturbing aspect of valuation efforts: "…the observation that if one summed the public's estimated values for individual environmental amenities, the sum may exceed disposable income" (p. 314). By implicitly ignoring the effects of joint production and policy interactions, such a procedure will systematically overstate benefits or understate costs. Recently, Randall (2002) proposed a strategy for addressing these issues, but to date, no empirical work is available. Therefore, in the empirical analysis that follows, it is necessary to assume that the cross derivative between E_1 and E_2 in the social value function for the externalities [$V(E_1, E_2, I)$, where I is real income] is small. Further, our policies are likely to have only a small effect on national income. Thus, we can approximate the value function as $V \cong B(E_1) - D(E_2)$.

The second issue relates to the E's being unobservable, in which case we assume that they are stochastic and are contingent on both L and Z. Then, as Shortle and Dunn (1986) point out, if $B(.)$ and $D(.)$ are replaced by their expected values, taxes and subsidies applied to all inputs affecting the E's are preferred to taxes and subsidies applied to forecasts of the E's.

that satisfy these first-order conditions are the ones that also satisfy

$$\alpha\left[B'\frac{\partial E_1}{\partial L} - D'\frac{\partial E_2}{\partial L} - s - (\overline{P} - P)\overline{Q}\right] - (1-\alpha)P_s = 0, \tag{8}$$

and

$$B'\frac{\partial E_1}{\partial Z} - D'\frac{\partial E_2}{\partial Z} + t = 0\,. \tag{9}$$

Solving equations (8) and (9) for *t* and *s* yields the following expressions for the optimal levels of the tax and subsidy:

$$t = D'\frac{\partial E_2}{\partial Z} - B'\frac{\partial E_1}{\partial Z}\,, \tag{10a}$$

and

$$s = B'\frac{\partial E_1}{\partial L} - D'\frac{\partial E_2}{\partial L} - (\overline{P} - P)\overline{Q} - \frac{1-\alpha}{\alpha}P_s\,. \tag{10b}$$

The intuition behind the two parts to equation (10) is straightforward: the optimal input subsidy (tax) is determined in part by the products of the marginal contributions of each input to the production of the externalities and the marginal benefit or damage of each externality. Thus, since both inputs contribute to the production of both externalities, it is impossible to determine *ex ante* if the subsidy (tax) is positive (negative). For example, the optimal tax for the non-land input may well be negative if that input's marginal contribution to the benefits associated with the positive externality outweighs its marginal contribution to the cost of damage associated with the negative externality. Whether the subsidy on land is positive or negative depends on similar considerations, but, in addition, the size of the land subsidy depends in part on the distorting effect of the limited price support and the land set-aside payment. To underscore the effect of market distortions on the level of "Pigouvian" type taxes or subsidies, it may be seen from equation (10b) that the land subsidy necessary to ensure the optimal level of the multiple externalities will decrease if the level of domestic support (either the price support or the set-aside payment) increases. Without the domestic support, the optimal subsidy for land is equal to the net effect of land's net marginal contribution to both externalities, similar to the results of Peterson, Boisvert, and de Gorter (2002).

Opening the Economy to International Trade

The optimal environmental policy design represented in equation (10) applies to a closed economy, and was applicable to the rice market prior to Taiwan's admission to the WTO, which, in 2003, led to rice imports under a tariff rate quota (TRQ). For this reason, we must also determine how the optimal multifunctional taxes and subsidies are affected by the new policy regime. To understand the TRQ, we follow the argument developed both algebraically and graphically by Abbott and Paarlberg (1998) for a small importing country. The small country assumption is justified in our case because the minimum annual commitment for imports of rice in Taiwan is only 50,652 tons. To model the TRQ regime, we must recognize that there are three possible outcomes. Under the first, where imports equal the minimum access commitment, the TRQ acts like a quota in which a tariff is also levied. Accordingly, the optimal environmental policy for this small open economy is similar to that in equation (10), except that the domestic price is now determined by the sum of domestic production plus imports, rather than by just domestic production as in the closed economy case. Second, if desired imports are less than the minimum access commitment, then the below quota tariff would be effective. The TRQ acts like a pure tariff in this case, and the domestic price is the world price plus the within in-quota tariff. For the third outcome, imports can exceed the minimum access level—in which case the higher out-of-quota tariff would apply.[8] As is seen in the empirical analysis below, it is the first outcome, where imports equal the minimum access commitment and the TRQ acts like a quota in which a tariff is also levied, that is applicable to the Taiwanese rice market.

Empirical Model

To illustrate the economic impact of policy changes, a computable partial equilibrium model is used to represent the Taiwanese rice market. This framework has been widely used for analyzing the effects of agricultural policies (Floyd 1965, Maier 1991, Gardner 1987). A special fea-

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[8] Both Krutilla (1991) and Peterson, Boisvert, and de Gorter (2002) demonstrate that the results for analyses of these types of trade policies are slightly different for the large country case because the government can exploit the terms-of-trade effect of policy intervention.

ture of the approach is that the various market levels in the vertical production/consumption chain are considered simultaneously. The approach is adopted primarily because agriculture represents only about two percent of Taiwan's domestic product—thus, it would be unlikely that there would be noticeable general equilibrium effects from changes in rice policy. Furthermore, similar partial equilibrium models have been used elsewhere to examine the effects of TRQs and the reduction in domestic agricultural support (e.g., Abbott and Paarlberg 1998, and Boughner and de Gorter 1999). Finally, as demonstrated above, the optimal environmental polices can be analyzed in conjunction with the adoption of a TRQ by making some rather straightforward changes in the partial equilibrium framework. In order to isolate the impact of trade liberalization, we examine scenarios for both a closed economy and an open economy. We benchmark our empirical model by assuming a closed economy with the domestic policies in place in 2001. We use 13 equations to characterize the essential features of the Taiwanese rice market (Table 1).

As with comparable models, data to estimate the parameters of input supply equations, etc., are not readily available. Thus, we employ reasonable estimates of the parameters derived from the literature, relying particularly on studies from Japan, other Asian countries, and the United States. As stated above, since a primary focus of the paper is on optimal environmental policies, we focus our sensitivity analysis of the empirical results on the range in estimates of environmental values.

Table 1. The Equations for the Taiwanese Rice Market

$$L = g_l(P_l) = k_l P_l^{\varepsilon_l} \tag{11}$$

$$Z = g_z(P_z) = k_z P_z^{\varepsilon_z} \tag{12}$$

$$FP = g_{fp}(P_{fp}) = k_{fp} P_{fp}^{\varepsilon_{fp}} \tag{13}$$

$$W = g_w(P_w) = k_w P_w^{\varepsilon_w} \tag{14}$$

$$\alpha F_l p + \alpha \overline{Q}(\overline{P} - P) + (1 - \alpha) P_s + \alpha s_l = P_l \tag{15}$$

$$PF_z = P_z \tag{16}$$

$$PF_{fp} = P_z + t \tag{17}$$

$$PF_w + s_w = P_w \tag{18}$$

$$\beta F(\alpha L, Z, FP, W) = \beta k_f (\alpha L)^{c_l} Z^{c_z} FP^{c_{fp}} W^{c_w} = Q^d \tag{19}$$

$$PP = k_p P \tag{20}$$

$$PP = a - b(Q^d + M) \tag{21}$$

$$GW = k_{gw} WTP \log\{W^{d_w} (\alpha L)^{d_l}\} \tag{22}$$

$$ME = k_m r W^{e_w} FP^{e_{fp}} (\alpha L)^{e_l} \tag{23}$$

Input Supply Equations

Equations (11) through (14) (Table 1) represent the supply system for inputs: farmland (*L*), farm labor (*Z*), fertilizer (*FP*), and irrigation water (*W*), respectively. The value used for the supply elasticity of land (ε_l) is 0.55. This is based on research for the Japanese rice industry (Ohba 2001) and is towards the low end of the range of 0.0 to 2.0 found in the literature (Floyd 1965, Gardner 1987). Individual irrigation associations have control over the allocation of irrigation, and the transfer of land in and out of agriculture must be approved by a government-sponsored, county-level farmers' organization. For this reason, we believe it is appropriate to assume a supply of land that is relatively inelastic to its price or rental value.

In past studies for the United States, estimates of the elasticity of labor supply to agriculture have ranged from 1.0 to 3.0 (Gisser 1971, Rosine and Helmberger 1974). A study by Tyrchniewicz and Schuh (1969) found labor supply elasticities ranging from around 0.7 in the short run to around 1.5 in the longer run. We assumed a value toward the low end of this range, 0.8, for the Taiwanese rice industry.[9]

Supplies of purchased inputs, such as fertilizer, are usually much more elastic than are those of other agricultural inputs. The range of fertilizer supply elasticities found in the literature is from

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[9] At the recommendation of a reviewer who noted that these estimates of the supply elasticity of labor are dated, we searched the literature for more recent estimates—to no avail. We did, however, perform some sensitivity analysis and determined that estimated changes in net social welfare and all other important variables from the model are extremely insensitive to changes in the supply elasticity for labor. There are two explanations for this result. The first, and perhaps most important, is that all policy impacts are compared to a 2001 baseline. To be consistent with this baseline, the model is initially calibrated using the assumed values for factor supply elasticities. All policy impacts are measured relative to this calibrated baseline. The second reason for the relative insensitivity of the results is that, as is seen below, labor is the only factor that does not contribute to the production of the environmental goods, and thus it is neither taxed nor subsidized in the optimal environmental policy.

0.5 to 10 (Gardner 1987). We assumed a supply elasticity of 2.0 for the Taiwanese rice industry.

We found no studies that provide empirical estimates of the supply elasticity of water for irrigation, but irrigation associations control most of the irrigation water used in rice production in Taiwan. Therefore, it seemed appropriate to assume that the supply of irrigation water would be quite unresponsive to the imputed value of water for rice production—so an elasticity of 0.3 is used in our analysis.

Input Demand Equations

Equations (15) through (18) (Table 1) are the derived input demand equations for farmland, labor, fertilizer, and water, respectively. These equations are derived from the first-order necessary conditions in the optimal decision model for rice farmers discussed above. Each variable is as defined in the theoretical model, and the additional term, F_i, is the partial derivative with respect to input i of the Cobb-Douglas production function, which is embedded in the market-clearing equation (19) (Table 1). As is discussed below, three of the inputs (fertilizer, land, and water) contribute to the production of the two environmental externalities. Thus, demands for these factors are affected by taxes or subsidies assigned to them by the government (t, s_l, and s_w, respectively). The demand for land is also affected by the level of price support, the set-aside payment, and the proportion of land that is set aside. Based on data published by the Council of Agriculture for 2001, the proportion of land suitable for paddy that is actually allocated to rice production (α) is around 0.7. In Taiwanese dollars (NT$), the government's purchase price for rice ($\bar{P}$) was NT$21,000/ton; the maximum amount that the government would purchase at this price was 1.26 tons/ha. The set-aside payment per hectare (P_s) was NT$41,000/ha (Council of Agriculture 2001). These policy parameters and environmental taxes and subsidies are set at various levels, or eliminated altogether, in the policy scenarios described below. In calibrating the model, the domestic policy variables are set at their 2001 levels, and the environmental taxes and subsidies are set to zero.

The Production Function, Rice Demand, and Market-Clearing Condition

Equation (19) (Table 1) is the market-clearing condition for rice production (the terms on both sides of the first equals sign) and consumption. We were somewhat limited in our choice of rice production functions because only time-series data on the cost of rice production were available. This is one of the primary reasons for specifying that the production function for rice has a Cobb-Douglas form. Another reason for the choice, however, is that the Cobb-Douglas form has performed well in several other studies where production functions were estimated from Taiwanese rice data (Tsai and Wann 1995). Since the production elasticities of the inputs for the constant returns to scale version of the Cobb-Douglas functional form are cost shares, we used time-series data on the cost of rice production between 1952 and 2001 to estimate the parameters of the production function. Average cost shares over that period for farmland, labor, fertilizer, and water were 0.19 (c_l), 0.57 (c_z), 0.22 (c_{fp}), and 0.02 (c_w), respectively.

In the market-closing condition, we also assume that there is a fixed proportional yield of table rice from raw rice. This is a common assumption for the relationship between vertical market levels in the industrial organization literature (Tirole 1988). Based on the conversion rate published by the Council of Agriculture in 2001, the value of β in equation (19) is set at 0.7. Equation (20) (Table 1) defines a fixed-proportion relationship between the farm price for rice and the consumer price.

Equation (21) (Table 1) is the linear demand function for rice. The consumer price is determined by the amount of rice available in the domestic market—domestic production in the autarky case and the sum of domestic production and imported rice (M) released onto the domestic market in the with-trade case. Parameter b is calibrated based on the assumption that the consumer demand elasticity for rice is -0.1 (Yang and Chen 2000). The low demand elasticity reflects the fact that rice is the main staple food in Taiwan; given the relatively high level of consumer income, demand is insensitive to changes in the price of rice.

Modeling the Environmental Externalities

Although non-trade concerns have traditionally figured in the debate on agricultural trade policy, the range of non-trade concerns has broadened dramatically in recent years. Much of this has been associated with the characterization of agriculture as a multifunctional activity. In this regard, Taiwan's identification of non-commodity outputs in paddy rice production is no exception.

Some of the issues identified in Taiwan are common to the production system used to grow rice throughout monsoon Asia.

In the monsoon environment, rice is grown in saturated soil that is often flooded throughout most of the growing season. In addition to providing optimum growing conditions for the rice, the production system has the potential to affect (positively and negatively) the natural environment. It may affect the frequency and intensity of flooding, groundwater recharge, soil erosion, and water and air quality. In addition, there may be important social and economic externalities relating to landscape and recreation. (See Blandford, Boisvert, and Fulponi [2003] for a broader discussion of multifunctional attributes.)

For this reason, and to be able to demonstrate the interaction between environmental policy designs within the context of domestic and international trade policy reform in agriculture, we focus on a single important positive externality (groundwater recharge) and a single important negative environmental externality (methane emission) associated with paddy rice production. These externalities are chosen not only because they are of particular interest in Taiwan's agricultural research and policy circles, but also because work exists relating to their non-market values.

The Positive Externality: Groundwater Recharge. One major consequence of the ponded conditions of paddy rice production is the percolation of water into the soil. The rate of percolation varies, depending upon soil type, but water moving downward has a recharge effect on groundwater. This will replace water withdrawn from the aquifer, raise the water table, or increase the outflow from the aquifer to springs, streams, or the sea (Ohnishi and Nakanishi 2001). It may also reduce substantially the risk of land subsidence (Barends, Brouwer, and Schroeder 1995). Recharge is influenced strongly by the status of the underlying aquifer. If the aquifer is in overdraft, i.e., the phreatic surface is declining over time, the recharge water may, according to some, be considered to have a value equal to that of water stored above ground. If the aquifer is not stressed by the rate of extraction, recharge may simply sustain the base flow of springs and streams fed from the aquifer. This may have significant environmental value, e.g., maintaining fish populations, but the value is likely to be lower than for an aquifer in overdraft.

The first step in modeling groundwater recharge is to specify how recharge relates to input use. Based on the findings from an agricultural engineering study of rice production (Matsuno et al. 2002), we assume that groundwater recharge is directly related to total land planted to paddy rice and the intensity of the application of irrigation water. Following a strategy similar to Peterson, Boisvert, and de Gorter (2002), we model groundwater recharge as a semi-logarithmic function, equation (22) (Table 1). By using this function, we are able to recognize that an increase in the intensity of the application of irrigation water per unit of land area will affect groundwater recharge, as will an increase in overall land use. We can see this by writing the term in braces from equation (22) as

$$\{(\frac{W}{\alpha L})^{2/3}(\alpha L)\}\ ,$$

which is also equal to $W^{2/3}(\alpha L)^{1/3}$. Thus, groundwater recharge increases with the use of both inputs (land and water), but at a decreasing rate. The non-market value of groundwater recharge is included in the model through equation (22) by multiplying the right-hand side of the equation by an estimate of the non-market value, willingness to pay (WTP).

For this analysis, the estimates for the value of groundwater (WTP) are derived from values reported by Chen (2001) and Chen, Wu, and Chang (2002). In both studies, contingent valuation methods (CVMs) are used to estimate the value of groundwater recharge associated with Taiwanese rice production. However, while Chen, Wu, and Chang (2002) focus only on the groundwater recharge value, Chen (2001) estimates the value of groundwater jointly with the value of other multifunctional outputs of rice production. Thus, it is difficult to disentangle the effects of groundwater recharge in this latter study. In an attempt to reconcile the two estimates of value, Boisvert et al. (2003) converted measures of total value to marginal values and generated estimates that were weighted by household type and county. Based on this analysis, the average willingness to pay for an additional one percent change in groundwater recharge was estimated to be NT$28,522, with an upper bound of NT$37,656 and a lower bound of NT$19,389. The range of the estimates of willingness to pay for groundwater recharge form the basis for a sensitivity analysis of the empirical results obtained from our model.

The Negative Environmental Externality: Methane Production. Although nitrate residuals are among the most widely recognized sources of agricultural pollution, there are numerous test results (e.g., from data supplied by the Kaoshung Irrigation Association) to suggest that current levels of nitrates in Taiwan's drinking water are within acceptable levels of concentration. For this reason, we focus on another issue—methane emissions from paddy rice fields.

Methane is produced during rice production by aerobic decomposition of soil organic material in flooded rice fields. Almost 90 percent of methane generated and oxidized by aerobic bacteria in the soil reaches the atmosphere, thus contributing to greenhouse gas emissions. In 1990, it was estimated that paddy rice contributed 16 percent of total methane emissions worldwide (U.S. Environmental Protection Agency [EPA] 1999). One important factor affecting methane generation is the water supply system; deepwater rice fields will generate significant amounts of methane. Some of the methane bubbles up through the water, but most reaches the atmosphere by traveling up the rice stalk through the plant's vascular system (Hyman 2001). For this reason, less methane is produced in upland areas because of the shortage of water during the rice production season (EPA 1999, 2002). Other factors that affect methane emissions from rice production are soil quality, soil temperature, fertilizer practices, and rice variety. For example, if farmers use biogas residues instead of barnyard manure in rice production, methane emission can be reduced by 24 to 62 percent. If farmers use hybrid rice seed, methane emission can be mitigated by 10 percent (Asia Development Bank 1998).

Because methane emissions involve an aerobic process, we assume that fertilizer, water, and land used in rice production contribute to methane emissions, as in equation (23) (Table 1). This specific formulation is based on estimates of total methane emissions by Yang (2000) and Lin et al. (2002). Average total emissions from rice production in these two studies were estimated to be 35,500 tons. Further, from a recent study of methane abatement in China (Asia Development Bank 1998), it is estimated that a one percent change in rice production will change methane emissions by roughly two percent. By combining these sources of information with the input production elasticities from the production function, we can relate methane emissions to input use.

The negative value of methane emissions to society is estimated as the product of average abatement cost (r in equation (23)) and total emissions. Our estimates of average abatement costs depend on the abatement technology available and on the total decrease in the amount of methane. According to a recent study of rice production in China, the most efficient abatement strategy is through effective manure management, involving an abatement cost of NT$2,890/ton; a much less efficient strategy is through the adoption of hybrid rice, with an abatement cost of NT$45,356/ton. Another possible strategy to decrease methane emissions is through the use of a dry nursery, for which the abatement cost is NT$13,600/ton (Asia Development Bank, 1998). Again, these values are used in evaluating the sensitivity of our results with respect to the social cost of methane emissions.

The Results of the Policy Analysis

Table 2 contains a summary of the parameter and policy variables used in the empirical model. After calibrating the functional constants k_i for each equation based on the observed data and the given parameters, we can solve for the optimal levels of the 13 endogenous variables (L, Z, FP, W, P_l, PZ, P_{fp}, P_w, Q^d, P, PP, GW, ME) simultaneously using equations (11) through (23).

Table 3 provides a summary of key results from the policy simulations. Columns A to C relate to

Table 2. Parameters and Policy Variables

Supply elasticity of land, $\varepsilon_l = 0.55$
Supply elasticity of labor, $\varepsilon_z = 0.80$
Supply elasticity of fertilizer, $\varepsilon_{fp} = 2.00$
Supply elasticity of water, $\varepsilon_w = 0.3$
Proportion of land for production, $\alpha = 0.71$
Ratio of raw rice to table rice, $\beta = 0.70$
Payment for land set aside, $P_s = 41{,}000$ (NT$/ha.)
Government purchase price, $\overline{P} = 21{,}000$ (NT$/T)
Government purchase quantity, $\overline{Q} = 1.268$ (T/ha.)
Production elasticity of land, $c_l = 0.19$
Production elasticity of labor, $c_z = 0.57$
Production elasticity of fertilizer, $c_{fp} = 0.22$
Production elasticity of water, $c_w = 0.02$
Contribution of water to groundwater recharge, $d_w = 0.67$
Contribution of land to groundwater recharge, $d_l = 0.33$
Elasticity of water to methane emissions, $e_w = 0.042$
Elasticity of fertilizer to methane emissions, $e_{fp} = 0.462$
Elasticity of land to methane emissions, $e_l = 0.40$

Table 3. Simulations of the Effects of Alternative Agricultural, Environmental, and Trade Policies on the Taiwanese Rice Market

	AUTARKY			LIMITED TRADE LIBERALIZATION		
	Current Support (A)	Support + Env. (B)	Green Policy (C)	Current Support (D)	Support + Env. (E)	Green Policy (F)
Optimal Environmental Policy						
Land subsidy (NT$/ha)	0	-3,084	339	0	-4,279	354
Water subsidy (NT$/ton)	0	0.0399	0.0401	0	0.0407	0.0363
Fertilizer tax (NT$/ton)	0	57	59	0	59	60
Resource Allocation	% Change from Base (A)					
Consumption (thousand tons table rice)	1,207	-0.1	0.3	0.5	0.3	0.7
Production (thousand tons raw rice)	1,724	-0.1	0.3	-3.7	-3.9	-3.5
Land planted to rice (1,000 ha)	332	0.0	7.6	-0.4	-0.4	4.6
Labor (1,000 persons)	231	0.5	-1.3	-3.9	-3.2	-4.8
Water (10^7 tons)	804	11.1	10.4	-2.1	9.8	8.0
Fertilizer (1,000 tons)	829	0.3	-2.4	-5.9	-5.2	-7.6
Groundwater recharge	278	5.9	9.5	-1.5	4.4	6.8
Methane emissions (10^3 tons)	35.5	-0.9	2.3	-3.0	-4.3	-1.5
Prices and Revenue						
Land rent (NT$1,000/ha)	27	-6.5	-38.9	-0.8	-9.9	-41.9
Wages (NT$1,000/person)	78	0.6	-1.6	-4.9	-4.0	-6.0
Fertilizer price (NT$1,000/ton)	8	0.2	-1.2	-2.6	-3.9	-8.6
Water price (NT$/ton)	0.08	41.9	39.1	-6.7	36.6	29.1
Farm price of rice (NT$1,000/ton)	18.3	1.3	-3.2	-5.2	-3.3	-7.3
Farm revenue (NT$\$10^{8}$)[a]	383	-1.7	-18.9	-8.9	-25.2	-16.7
Welfare Analysis						
Consumer surplus (NT$\$10^{10}$)	19.7	-0.3	0.6	1.0	0.7	1.5
Producer surplus (NT$\$10^{10}$)	2.1	-1.9	-21.4	-5.7	-8.9	-27.6
Domestic payments (NT$\$10^{7}$)	674	-5.0	-93.6	5.5	-17.2	-94.2
Groundwater recharge value (NT$\$10^{7}$)	947	0.3	0.5	-0.1	0.2	0.3
Methane emission value (NT$\$10^{7}$)	10.3	-0.9	2.3	-3.0	-4.3	-1.5
Social welfare (NT$\$10^{10}$)	22.1	0.1	1.4	0.7	0.5	2.1

[a]Includes domestic policy payments.

simulations performed under the assumption of autarky, and Columns D to F reflect limited imports whose allocation is controlled by the state trading entity.[10]

Columns A and D provide the bases for comparison under the closed economy and limited trade options, in that each relates to the "current support" case—a price and income support policy with a land set-aside. Columns C and F relate to the case in which price and income support objectives are abandoned, being replaced by a policy in which environmental objectives alone are pursued. To provide a further point of comparison, columns B and E show what happens if the government keeps its existing price and income support instruments, but also uses subsidies and taxes to address the environmental externalities.

The key conclusions that can be drawn from these results are as follows:

- Achieving environmental objectives by replacing the current price support policies with environmental policies would require the payment

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[10] In all simulations where limited imports are allowed under the tariff rate quota, the quota is binding (e.g., imports are equal to the minimum access commitment). Since the lower, in-quota tariff rate is set at zero in Taiwan, there are no tariff revenues collected.

of land and water subsidies, and the imposition of a tax on fertilizer. Under the valuations assumed for the environmental goods, water use would expand by about 9.5 percent and the value of groundwater recharge would also increase. Fertilizer use would decline by about 2.4 percent. The amount of land in rice production would rise by 7.6 percent, in part to foster the increase in groundwater recharge.

- Contrary to what one might expect, this policy re-instrumentation would actually increase rice production slightly, and the amount of land in rice production would rise by 7.6 percent, in part to foster the increase in groundwater recharge. As mentioned above, this result is due in large part to the design of the pre-WTO price support policy. The support price was paid only on a fixed quantity of production per hectare. Thus, even prior to policy reform, the supply-inducing price at the margin was the domestic market-clearing price, rather than the support price.

- The replacement of price and income support objectives by environmental objectives has significant redistributive implications. There is a substantial reduction in transfers to producers: since the current large payments to producers are not needed to achieve the environmental benefits/reduce the environmental costs associated with rice production, the domestic payments fall by 93.6 percent. The elimination of income support, in the form of set-aside payments and government purchases of rice, causes imputed land rents to decline substantially, by an estimated 38.9 percent.

- The pursuit of environmental objectives is welfare-enhancing under all the cases analyzed. Producers lose, consumers gain, and government payments are reduced. Net social welfare increases once environmental externalities are internalized in the autarky case, but the gains are higher under trade liberalization. This is consistent with the view that trade liberalization is welfare-enhancing overall, and suggests that, at least for the case analyzed, the pursuit of environmental aims is not inconsistent with freer trade.

- The joint pursuit of redistributive and environmental objectives is inferior, in terms of net social welfare, to a policy that attempts to achieve environmental objectives alone. Because the multifunctional non-commodity outputs are not produced in fixed proportion with agricultural output, the compensation of producers associated with the income support objective implicitly values groundwater recharge below its social value and underestimates the social cost of methane abatement. This is best seen by the magnitude of the environmental taxes and subsidies in the presence of domestic distortions created by existing policies. Given these distortions, environmental objectives can be achieved only through a land tax, rather than a land subsidy, in conjunction with a water subsidy.

The results in Table 3 were derived using the mean of the valuation for groundwater recharge (WTP = NT$28,522) and with the cost of methane emissions associated with the most efficient management strategy (Me = NT$2,890). In order to examine the robustness of our conclusions, we conducted a sensitivity analysis using the closed-economy scenario as a point of reference (Table 4). The results in Table 4 are obtained using the high and low valuations, respectively, from willingness to pay studies, as derived by Boisvert et al. (2003). The abatement costs associated with methane emissions are unchanged from those used in generating the results in Table 3 for these two simulations. The table also gives the results obtained when the alternative high and very high abatement costs, associated with alternative management strategies discussed above, are assumed. The valuation attached to groundwater recharge is that used in deriving the results in Table 3.

The key points to be drawn from the sensitivity analysis are as follows:

- As might be expected, a lower valuation for groundwater recharge results in a reduction in the land and water subsidies required to achieve environmental objectives; a higher valuation results in larger subsidies.

- As the economic costs associated with methane emissions increase, the optimal tax on fertilizer rises, and land subsidies are replaced by land taxes. These measures are needed to reduce the amount of land under rice cultivation, and the production of rice.

- Although the net effect varies, social welfare is increased by the pursuit of environmental objectives in comparison to current policies.

Table 4. Sensitivity of the Policy Simulations to Alternative Values for the Environmental Variables

	Scenarios with Alternative Environmental Values[a]					
	(A)	(C)	(G)	(H)	(I)	(J)
Parameter Value						
WTP	--	28,522	37,656	19,389	28,522	28,522
Me	--	2,890	2,890	2,890	13,600	45,356
Optimal Environmental Policy						
Land subsidy (NT$/ha)	0	339	486	193	-97	-1390
Water subsidy (NT$/ton)	0.00	0.0401	0.0462	0.0249	0.0339	0.0282
Fertilizer tax (NT$/ton)	0.0	59.3	59.3	59.3	279.0	930.3
Resource Allocation	% Change From Base (A)					
Production (thousand tons raw rice)	1,724	0.3	0.3	0.3	0.2	-0.1
Land planted to rice (1,000 ha)	332	7.6	7.9	7.4	7.0	5.1
Labor (1,000 persons)	231	-1.3	-1.4	-1.2	-0.8	0.4
Water (10^7 tons)	804	10.4	11.9	6.5	9.0	8.0
Fertilizer (1,000 tons)	829	-2.4	-2.5	-2.2	-3.4	-6.4
Groundwater recharge	278	9.5	10.6	6.8	8.3	7.1
Methane emission (10^3 tons)	35.5	2.3	2.4	2.1	1.5	-0.7
Prices and Revenue						
Imputed land rent (NT$1,000/ha)	27.2	-38.9	-38.6	-39.1	-39.5	-41.4
Wages (NT$1,000/person)	77.8	-1.6	-1.7	-1.5	-1.1	0.5
Fertilizer Price (NT$1,000/ton)	8	-1.2	-1.3	-1.1	-1.7	-3.3
Water price (NT$/ton)	0.08	39.1	45.5	23.2	33.3	29.4
Farm price of rice (NT$1,000/ton)	18.3	-3.2	-3.4	-2.9	-2.1	1.1
Farm revenue ($\text{NT}\$10^{8}$)[b]	382.5	-18.9	-18.7	-19.2	-19.1	-19.3
Welfare Analysis						
Consumer surplus ($\text{NT}\$10^{10}$)	19.70	0.6	0.7	0.6	0.4	-0.2
Producer surplus ($\text{NT}\$10^{10}$)	2.10	-21.4	-21.1	-21.9	-21.6	-21.7
Domestic payments ($\text{NT}\$10^{7}$)	674	-93.6	-92.0	-96.5	-99.4	-114.3
Groundwater recharge value ($\text{NT}\$10^{7}$)	947	0.5	32.7	-31.8	0.4	0.4
Methane emission value ($\text{NT}\$10^{7}$)	10.3	2.3	2.4	2.1	377.5	1458.1
Social welfare ($\text{NT}\$10^{10}$)	22.1	1.4	2.8	0.0	1.2	0.6

[a] Scenarios A and C are the same as those in simulations A and C in Table 3. Scenarios G, H, I, and J embody the same assumptions as scenario C, except for the parameter values for WTP and Me indicated above.

[b] Includes domestic policy payments.

The substantial redistributive impact of the change in policy aims (as evidenced by the reduction in producers' surplus and land rents) remains.

Policy Implications

The approach developed in this paper demonstrates how optimal policies for the supply of non-commodity (environmental) attributes associated with Taiwanese rice production can be determined. We have shown that a policy aimed at securing an appropriate supply of a major positive attribute—groundwater recharge—and containing a negative attribute—methane emissions—would require policy re-instrumentation. Taxes and subsidies on inputs used in rice production would need to replace the price and income support measures currently used. We have also shown that the modest liberalization of trade that has taken place since Taiwan joined the World Trade Organization is not inconsistent with achieving key environmental objectives. Recognizing that the specific numerical results are sensitive to parameter values, we have demonstrated the robustness of the qualitative conclusions on appropriate policy design under substantial variation in the valuation parameters for environmental attributes.

Although the results obtained may not be generally applicable to other countries and agricultural systems, we believe that they shed some light on two important issues surrounding the debate on multifunctionality.

The first is that a policy approach that treats non-commodity attributes in agriculture as secondary objectives to existing aims, such as income support, may well result in sub-optimal outcomes. As the Taiwan case demonstrates, it does not follow that the pursuit of income support goals through the use of traditional policy measures will result in the desired supply of environmental goods. It may be possible to achieve that supply at far lower costs, both to the government and to society as a whole, if policy instruments are employed that are more suited to achieving environmental goals than existing measures. If it is indeed the case, as some would argue, that agriculture's role in the supply of environmental goods is increasingly important, it may not be appropriate or sufficient to make marginal adjustments in the settings of existing agricultural policy instruments to achieve the desired outcome; a more radical redesign of policy may be required. This may have significant redistributive implications, particularly through reductions in income and asset values at the farm level. Consideration may have to be given to addressing these issues if the redesign of policy is to be politically feasible and is to help control farmers' entry and exit from agriculture.

A second issue illuminated by our analysis is that agricultural trade liberalization may not be inconsistent with the pursuit of domestic environmental objectives. Put differently, our results provide empirical evidence supporting the early arguments by Bhagwati and Ramaswami (1963), as well as others, that trade policy should not be used to correct domestic distortions. In our context, the distortions created by the lack of markets for the positive and negative externalities associated with agricultural production are best addressed directly through domestic taxes and subsidies on inputs, while at the same time allowing consumers to benefit from lower product prices resulting from reduced import protection. The maintenance of high product prices through import protection seems an inefficient way to achieve environmental aims, and could run counter to achieving those aims.

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