THE IMPLICATIONS OF GEOGRAPHIC HETEROGENEITY FOR MULTIFUNCTIONAL RICE POLICY IN TAIWAN

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INTRODUCTION

As in many other countries, the debate on agricultural policy in Taiwan is shifting from the traditional focus of farm income support to ensuring the provision of non-commodity (multifunctional) agricultural outputs. In this paper, we examine the re-instrumentation of Taiwanese rice policy to ensure optimal levels of two such outputs (the positive attribute of groundwater recharge and the negative attribute of methane emissions), taking into account spatial heterogeneity in resources and the productive environment (e.g., Lichtenberg, 2004). We examine the implications of implementing a policy at the regional level compared with a uniform national policy. We also consider the implications of transboundary issues. Finally we estimate the costs of compensating Taiwanese rice farmers for the loss in the value of farm assets due to policy reorientation.

THEORETICAL MODEL

Chang, *et al.* (2005) outlined a conceptual framework for multifunctional policy design for Taiwanese rice. We expand this to account for geographic heterogeneity and transboundary effects.[1] To identify optimal policies, a partial equilibrium model is solved in two stages by backward induction.

In stage 2, the producer in region i (i = 1,..,I) maximizes profit under given domestic policies:

$$\underset{L_i, Z_i}{Max}\ \pi_i = p\{F_i(\alpha L_i, Z_i) - \alpha_i L_i \overline{Q}\} + \alpha_i L_i \overline{P}\overline{Q} + (1-\alpha_i) L_i P_s - P_{Li} L_i - P_{Zi} Z_i + s_i(\alpha_i L_i) - t_i Z_i \quad (1)$$

where $F_i(.)$ is the rice production function in region i; p is the national market

[1] Copeland (1996), and Copeland and Taylor (1999) illustrate how to model transboundary effects.

equilibrium price for rice. L_i and Z_i are land and the other purchased inputs of rice production in region *i*, respectively, with the price of land (P_{Li}), and the price of a purchased input (P_{Zi}).[2] The proportion of agricultural land in region *i* in production is α_i; the proportion in set-aside is (1-α_i). $\overline{P}$ is the per unit price for program rice, $\overline{Q}$ is the government purchase quantity per hectare, P_s is a per hectare set aside payment.[3] Because of difficulties in observing levels of multifunctional externalities, policies are designed to affect the use of all inputs used in their production; s_i is the compensation to land and t_i is a fee assessed on the use of the purchased input.[4] The first-order conditions for an interior solution are (for i =1,…,I):

$$\frac{\partial \pi_i}{\partial L_i} = \alpha_i p \frac{\partial F_i}{\partial L_i} + \alpha_i \overline{Q}(\overline{P} - p) + (1-\alpha_i)P_s + \alpha_i s_i - P_{Li} = 0 \qquad (2)$$

$$\frac{\partial \pi_i}{\partial Z_i} = p \frac{\partial F_i}{\partial Z_i} - t_i - P_{Zi} = 0 . \qquad (3)$$

The marginal return from using an additional unit of each input is equated to its regional price (including any regional compensation, s_i or fee, t_i, due to the input's contribution to multifunctional outputs).

In stage 1, payments (subsidies) and fees (taxes) on inputs are set to maximize net social welfare – the sum of consumers' and producers' surplus, plus the net social value of environmental externalities, less the cost of the domestic programs. The government's decision problem is to maximize:

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[2] For simplicity, and without loss of generality, this theoretical discussion is limited to two farm inputs.
[3] Chang, *et al.* (2005) describe the domestic limited-purchase price support and land set-aside programs.
[4] Peterson, *et al*. (2002) demonstrate that this type of policy is equivalent to one in which a fee (compensation) is related directly to multifunctional output equal to its marginal social cost (value).

$$\underset{(s_i,t_i)}{SW} = \int_0^{Q_c} p(h)dh - p(Q_c)(Q_c) + \sum_{i=1}^{I}\pi_i + \sum_{i=1}^{I} B_i[G_i(\alpha_i L_i, Z_i) + \sum_{j\neq i}^{I} \beta_{ji} G_j(\alpha_j L_j, Z_j)]$$

$$+ \sum_{i=1}^{I} D_i[M_i(\alpha_i L_i, Z_i) + \sum_{j\neq i}^{I} \gamma_{ji} M_j(\alpha_j L_j, Z_j)]$$

$$-\sum_{i=1}^{I}[s_i(\alpha_i L_i) + t_i Z_i - \alpha_i L_i \overline{Q}(\overline{P} - p) - (1-\alpha_i)L_i P_s] \quad (4)$$

where $p(h)$ is the inverse demand curve for rice; $p(Q_c)$, market price is evaluated at equilibrium consumption, including imports,[5] and π_i is the farmer's indirect profit function in region i. The transboundary effects generated by region (j) are captured by the parameters (β_{ji}) and (γ_{ji}) for positive and negative externalities, respectively. The function B_i (.) defines the total benefit from the positive environmental externality and the function D_i (.) gives the total damage from the negative externality in region i. The first two terms of equation (4) represent consumers' surplus. The 3rd term represents farm profit and the 4th and 5th terms are social benefits and costs of the positive and negative externalities. The remaining terms sum net government payments. After applying Shephard's lemma to equation (4) and rearranging terms, optimal multifunctional payments and fees for region i are:

$$s_i = B_i'[\frac{\partial G_i}{\partial L_i} + \sum_{j\neq i}^{I}\beta_{ji}\frac{\partial G_j}{\partial L_j}] - D_i'[\frac{\partial M_i}{\partial Z_i} + \sum_{j\neq i}^{I}\gamma_{ji}\frac{\partial M_j}{\partial Z_j}] - (\overline{P} - p)\overline{Q} - \frac{1-\alpha_i}{\alpha_i}P_s; \quad (5)$$

$$t_i = D_i'[\frac{\partial M_i}{\partial Z_i} + \sum_{j\neq i}^{I}\gamma_{ji}\frac{\partial M_j}{\partial Z_j}] - B_i'[\frac{\partial G_i}{\partial L_i} + \sum_{j\neq i}^{I}\beta_{ji}\frac{\partial G_j}{\partial L_j}]. \quad (6)$$

The optimal payment (or fee) per unit is determined by the marginal contribution of each input to social welfare, including marginal environmental value. Social welfare is

[5] Since 2001, rice is imported to Taiwan under a Tariff Rate Quota (TRQ). Because of the high out-of-quota

maximized only if domestic policy instruments are zero.[6] Furthermore, if there are regional differences in the production and benefit or damage functions, the regional magnitudes of payments and fees will differ. Optimal values must account for marginal transboundary benefits or costs.

EMPIRICAL MODEL

We examine the effects of geographic heterogeneity by using a four-region model of the Taiwanese rice market (Table 1).[7] Equations (7) - (19) define regional supplies of farmland (L), farm labor (Z), fertilizer (FP), and irrigation water (W), respectively. We assume a single national market for fertilizer and that other inputs cannot move between regions. The supply elasticities for farm inputs, based on Chang, *et al*. (2005), are in Table 2.

Equations (20) - (35) are the regional derived input demands, where F_k is the partial derivative of the production function; the subscript k denotes the specific input and region. Since all inputs contribute to the two environmental externalities, their demands are affected by fees or payments that differ by region (t_i, s_{li}, and s_{wi}, respectively). The demand for land is also affected by the price support, the set-aside payment, and the proportion of land that is set aside, when these instruments are used. Their base levels (some of which differ regionally) are from published Council of Agriculture (CoA) data (Table 2). Combinations of environmental taxes and subsidies are set at various levels in the scenarios described below. In the base solution, domestic

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tariff, the TRQ acts like a pure quota system.

[6] It is impossible to maximize social welfare using only the domestic support programs because the domestic policy variables ($\overline{P}, \overline{Q}, P_s$) affect only the land subsidy but not the fee on the purchased input. It is not possible to find values for ($\overline{P}, \overline{Q}, P_s$) that satisfy equations (5-6) if s_i and t_i are zero.

[7] The general framework is similar to that used by Gardner (1987).

policy variables are set at their 2001 levels and environmental payments and fees are zero.

Equations (36) - (39) are regional Cobb-Douglas paddy rice production functions. They are estimated from 2001-2003 farm household survey data on costs of production published by CoA (Table 2). An input's production elasticity is the input's cost share. Equations (40) - (42) are market clearing conditions. Equation (42) is the consumer demand function, and equation (41) defines the fixed proportional relationship between farm and consumer prices.

As noted above, two environmental externalities are considered: groundwater recharge and methane emissions. Equations (43-46) specify the relationships between groundwater recharge and the use of inputs. Farmland and irrigation water are assumed to affect the irrigation system (pumping), and thus determine groundwater recharge. Following an approach similar to Peterson, *et al*. (2002), this is captured through a semi-logarithmic function. An increase in the intensity of water application per unit of land area will affect groundwater recharge, as will an increase in overall land use. The effect of soil quality on the rate of percolation, measured in mm/day (Matsuno, *et al*. 2002), is also reflected. The regional values in Table 2 are county averages, weighted by paddy acreage. Regional infiltration rates differ only slightly.

The social value of groundwater (*WTP*) from Chang, *et al.* (2005) is based on the assumption that an aquifer is in overdraft. We assume that willingness to pay (*WTP)* for recharge of other aquifers is 25% of that value. The values in Table 2 reflect the fact that most aquifers in the North and the South are in overdraft, while most in the East are not.

Equations (47-50) relate to regional methane emissions from paddy rice production. Following Chang, *et al*. (2005), the elasticities of emission with respect to fertilizer, irrigation water, and land are in Table 2. The social value of methane emissions (Table 2) is based on estimates of abatement costs from the Asian Development Bank (ADB 1998). When considering transboundary effects, we assume that regional emissions impose social costs on other regions in Taiwan, and that these are inversely related to the distance from the source of the emissions. In equation (51), for example, the spillover effects of other regions to region 1 are 0.6 (ρ_{21}); 0.4 (ρ_{31}) and 0.1 (ρ_{41}).[8]

OPTIMAL MULTIFUNCTIONAL POLICIES

Tables 3 and 4 summarize the results of three policy scenarios. The first assumes that the current domestic support program for rice is replaced by a multifunctional policy in which payments and fees are differentiated regionally. The second scenario uses national payment rates and fees, set equal to the production-weighted averages of the regional policy instruments from the first scenario. The third scenario allows for regional policy differentiation with transboundary emissions costs.

Table 4 gives regional and national percentage changes from the baseline for key variables. The baseline is one in which the current price support program for rice, with its associated land set-aside provisions, is in place and there are no imports. The variables listed are rice production, the amounts of land and labor used, farm revenue, government payments, the imputed value of land in rice production (land rental), in addition to changes in groundwater recharge and social costs of methane emissions. All scenarios assume limited imports of rice as required by Taiwan's accession agreement to the WTO..

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[8] Even though one might argue that the social costs of methane's contribution to greenhouse gasses do not diminish with distance from the source, we use this weighting scheme primarily to illustrate the importance of differential transboundary effects. Such a weighting scheme would certainly be more appropriate for other types of toxic air pollutants, e.g., sulfur dioxide (SO_2) and nitrogen oxides (NO_x), that affect local air quality and human health, but whose effects diminish with distance from the source.

Some of the key lessons from the results in Tables 3 and 4 are:

- When geographic heterogeneity is taken into account (scenario 1), optimal taxes and subsidies on inputs differ substantially across regions. A modest implicit subsidy on land is required in most regions, and positive subsidies for water and taxes for fertilizer. Under the optimal policy rice production falls in three regions, but increases slightly in the North (the region with the highest set-aside in the baseline). The same is true for land, water, and labor allocated to rice production. Gross farm revenue falls in all regions, although the decrease is most dramatic in the North in spite of higher production. This region receives the largest benefits from the current price support and set aside policies (Table 2). This explains why the reduction in land rents is also highest in the North.
- An undifferentiated approach (scenario 2), in which payments and fees are set at the same level in each region, is relatively efficient in producing the necessary changes in rice production and resource use (Table 4). This result is relevant to controlling the administrative costs of multifunctional policies. However, it is important to stress that the levels of the instruments in this case are production-weighted averages of optimal regional values. It is important to choose national values that are as close as possible to regional optima if potential inefficiencies are to be minimized.
- Taking transboundary effects into account (scenario 3) can be important. This is particularly evident for the North. The social cost of methane emissions for this region (where much of Taiwan's population lives) is only reduced when

the taxes on land and fertilizer use are increased sufficiently to reduce the overall level of emissions. The implication is best seen by comparing the changes in “regional” and “national” social costs of methane in Table 4.

As noted in Table 3, all the policy scenarios examined lead to small increases in social welfare. By letting policy instruments differ and taking into account transboundary issues, social welfare is maximized, providing there are no administrative costs.

ADJUSTMENT TO MULTIFUNCTIONAL POLICIES

The results in Table 4 indicate that the shift away from the current price support program would result in a significant fall in gross farm revenue and the implied value of land. In some countries, time-limited payments have been used to ease the adjustment process resulting from domestic policy reform. Australia used such payments in reforming its domestic dairy policies (Harris and Rae, 2006). Payments were made to the holders of marketing quotas for peanuts as part of the introduction of a more market-oriented program under the 2002 US Farm Act (Dohlman, *et al*., 2006).

To gain a perspective on the implications of providing adjustment assistance, we assume that Taiwanese rice farmers are compensated for losses in land values due to the reduction in price supports and land set-aside payments. Focusing on scenario 1, annual returns to land are estimated to fall by an average of nearly 56% nationally (the change in land rent from Table 4). To compensate for this, an average direct payment of about $NT15,000/ha. would be required. Payments would be highest in the North (NT$27,900/ha.), and lowest in the Center Region (NT$9,200) In the East and South, they would be NT$15,600 and NT$16,800, respectively. If payments were made only on land in production, the cost would be $NT4.6 billion, or 61% of the annual outlay under the price support program. If payments were also made on land currently in set-aside, the cost would rise to $NT6.6 billion or 88% of the current budget outlays. In that case, regional payments would differ dramatically, primarily because of the relatively large set aside area in North. Payments would be 117%, 76%, 87% and 84% of the annual government outlays for traditional policies for the North, Center, South, and East regions, respectively.

While a one-time payment would compensate producers for a single year's reduction in returns to land, it would not account for a stream of losses over several years. To address this, the government could make a series of annual payments for a fixed number of years into the future. Such time-limited, decoupled payments would qualify as Green Box payments under the WTO's Agreement on Agriculture.

CONCLUSIONS

Multifunctional policy objectives for Taiwanese rice, defined with respect to maintaining groundwater recharge and reducing methane emissions, can be achieved at lower costs than existing price and income support policies, even if compensatory payments are made for reductions in asset values. Social welfare gains are maximized through the use of regionally differentiated payments and fees, particularly when the transboundary effects of methane emissions are considered. It may be possible to achieve most of these gains with uniform national payments, providing that these are set at appropriate levels. This could be important if the administrative costs of a regionally-differentiated approach are significant.

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Table 1. Equations for the Empirical Model

$$L_i = k_{L_i} P_{L_i}^{\varepsilon_L} \ ; \ Z_i = k_{z_i} P_{z_i}^{\varepsilon_z} \ ; \ W_i = k_w P_{w_i}^{\varepsilon_w} \ ; \ \text{(i=1,…,4)} \ FP = \sum_{i=1}^{4} FP_i = k_{fp} P_{fp}^{\varepsilon_{fp}} \quad \text{(7-19)}$$

$$\alpha_i F_{L_i} p + \alpha_i \overline{Q}(\overline{P} - p) + (1-\alpha_i) P_s + \alpha_i s_{L_i} = k_{P_{Li}} P_{L_i} \ ;$$

$$pF_{z_i} = k_{P_{zi}} P_{z_i} \ ; \ pF_{fp_i} = k_{P_{fpi}} P_{fp_i} + t_i \ ; \text{ and } \ pF_{w_i} + s_{w_i} = k_{P_{wi}} P_{w_i} \quad \text{(i=1,…,4)} \ \text{(20-35)}$$

$$\beta_i F_i(\alpha_i L_i, Z_i, FP_i, W_i) = \beta_i k_{fi} (\alpha_i L_i)^{c_{Li}} Z_i^{c_{zi}} FP_i^{c_{fpi}} W_i^{c_{wi}} = Q^d{}_i \quad \text{(i=1,,4)} \quad \text{(36-39)}$$

$$Q^d = \sum_{i=1}^{4} Q^d{}_i \quad \text{(40)}$$

$$PP = k_p P \quad \text{(41)}$$

$$PP = a - b(Q^d + M) \quad \text{(42)}$$

$$GW_i = k_{gwi} WTP_i \log\{W_i^{d_w} (\alpha_i L_i)^{d_l} \, soil_i\} \quad \text{(i=1,…,4)} \quad \text{(43-46)}$$

$$ME_i = k_{mi} r W_i^{e_w} FP_i^{e_{fp}} (\alpha_i L_i)^{e_l} \quad \text{(i=1,…,4)} \quad \text{(47-50)}$$

$$ME = \sum_{i=1}^{4} r k_{mi} W_i^{e_w} FP_i^{e_{fp}} (\alpha_i L_i)^{e_l} (1 + \sum_{j \neq i}^{3} \rho_{ij}) \quad \text{(51)}$$

Table 2. Parameters and Policy Variables				
Parameters	**National Values**			
Supply Elasticities				
Land	0.550			
Labor	0.800			
Water	0.300			
Fertilizer	2.000			
Elasticity of recharge/land use	0.330			
Elasticity recharge/water use	0.670			
Elasticity of methane/water use	0.042			
Elasticity of methane/fertilizer use	0.462			
Elasticity of methane/land use	0.462			
Methane abatement cost (NT$/T)	2,890			
Ratio of table rice to raw rice	0.700			
Government purchase price (NT$/T)	21,000			
Set-aside payment (NT$/ha)	41,000			
	Regional Parameter Values[a]			
	North	Center	South	East
Government purchases (tonnes/ha)	2.11	1.28	1.02	0.79
Production Elasticities				
Land	0.180	0.168	0.128	0.138
Labor	0.620	0.605	0.614	0.612
Water	0.027	0.024	0.032	0.028
Fertilizer	0.173	0.203	0.225	0.223
Willingness to pay (WTP_i) for GWR (NT$)[b]	25,436	14,974	25,412	2,074
Proportion of rice land in production	0.46	0.85	0.65	0.67
Water infiltration rate (mm/day)	3.478	3.605	3.578	3.725

a The counties included in the regions are: North: Keelung, Taipei, Yilan, and Taoyuan; Center: Hsinchu, Miaoli, Taichung, Changhwa, Nantou, and Yunlin; South: Chiayi, Tainan, Kaohsiung, and Pingtung; East: Taitung and Hwalien.

b We assume that the *WTP* for groundwater recharge (GWR) when aquifers are not in overdraft is 25% of that of aquifers in overdraft.

Using unpublished data from the Water Resources Agency, Ministry of Economic Affairs, Taiwan, we calculated the proportion (OD_i) of sample points in region's aquifers that are in overdraft to derive a weighted average WTP, and multiplied that figure by the proportion of the Taiwanese population in the region.

$WTP_i = [(OD_i)\, WTP + (0.25)\,(1- OD_i)\, WTP] * Pop_i / Pop_T$;

WTP is from Chang, *et al*. (2005).

Table 3. Levels of Multifunctional Policy Instruments				
	Regions			
	North	**Center**	**South**	**East**
Scenario 1. MF	National Social Welfare: +1.6% Δ from base			
Land Subsidy (NT$/ha)	127	78	72	-112
Water Subsidy (NT$/ton)	0.014	0.014	0.038	0.001
Fertilizer Tax (NT$/ton)	85	227	77	64
Scenario 2. NMF	National Social Welfare: +1.6% Δ from base			
Land Subsidy (NT$/ha)	68	68	68	68
Water Subsidy (NT$/ton)	0.015	0.015	0.015	0.015
Fertilizer Tax (NT$/ton)	152	152	152	152
Scenario 3. MF+TB	National Social Welfare: +2.5% Δ from base			
Land Subsidy (NT$/ha)	-24	-177	-106	-289
Water Subsidy (NT$/ton)	0.013	0.012	0.037	-0.000
Fertilizer Tax (NT$/ton)	258	350	286	209

All scenarios assume limited rice imports as defined by Taiwan's accession agreement to the WTO:
MF = regionally-differentiated payments and fees;
NMF = payments and fees equal to production-weighted averages of the regional policy instruments;
TB = the transboundary effects of methane emissions are taken into account.
Note that an absolute value of 0.000 in the table denotes that the water subsidy is less than 0.0005 in absolute value.

Table 4. Regional Effects of Policy Scenarios

	Regions				
Scenarios	**North**	**Center**	**South**	**East**	**Nation**
	---------- % change from base case ----------				
Rice Production					
Scenario 1. MF	2.0	-5.4	-3.7	-4.1	-4.1
Scenario 2. NMF	1.6	-4.8	-4.6	-3.9	-4.1
Scenario 3. MF+TB	2.1	-5.2	-4.5	-4.0	-4.2
Land Planted to Rice					
Scenario 1. MF	7.7	-11.5	-11.5	-12.1	-9.3
Scenario 2. NMF	7.2	-11.4	-11.8	-11.4	-9.3
Scenario 3. MF+TB	7.4	-11.8	-12.1	-12.4	-9.7
Amount of Groundwater					
Scenario 1. MF	0.4	-0.1	-0.1	-0.3	-0.1
Scenario 2. NMF	0.4	-0.1	-0.2	0.2	-0.1
Scenario 3. MF+TB	0.4	-0.2	-0.1	-0.3	-0.1
Regional Social Cost of Methane					
Scenario 1. MF	4.2	-8.2	-6.3	-6.7	-5.8
Scenario 2. NMF	3.3	-7.3	-7.7	-6.6	-6.2
Scenario 3. MF+TB	3.6	-8.4	-8.1	-7.2	-6.8
National Social Cost of Methane					
Scenario 3. MF+TB	-5.6	-7.1	-7.4	-7.8	-7.0
Labor Use					
Scenario 1. MF	0.3	-3.1	-2.3	-2.5	-2.3
Scenario 2. NMF	0.0	-2.8	-2.7	-2.4	-2.3
Scenario 3. MF+TB	0.7	-2.5	-2.2	-2.0	-2.0
Gross Farm Revenue					
Scenario 1. MF	-38.3	-15.4	-24.1	-24.1	-21.7
Scenario 2. NMF	-38.7	-14.9	-25.2	-22.9	-21.7
Scenario 3. MF+TB	-37.9	-14.7	-24.2	-23.5	-21.3
Government Payments					
Scenario 1. MF	-99.0	-101.2	-98.7	-100.7	-99.7
Scenario 2. NMF	-99.3	-99.8	-100.6	-96.9	-99.7
Scenario 3. MF+TB	-99.9	-105.3	-101.4	-103.9	-102.3

Table 4. Regional Effects of Policy Scenarios (continued)

	Regions				
Scenarios	**North**	**Center**	**South**	**East**	**Nation**
	---------- % change from base case ----------				
Land Rent					
Scenario 1. MF	-71.9	-40.2	-62.7	-60.9	-55.8
Scenario 2. NMF	-72.1	-40.0	-62.9	-60.3	-55.7
Scenario 3. MF+TB	-72.0	-40.6	-63.1	-61.1	-56.1

The scenarios are defined in Table 3. The percentage changes are with respect to a "base case" in which current domestic support and land set aside policies are in place, and imports of rice are not permitted. For the base case, Taiwan has about 332,000 hectares planted to rice, with rice production totaling over 1.7 million tons. Just over 136,000 hectares are in the set-aside program, and about 231,000 people are involved in production. Annual government payments total about NT$7.5 billion, with nearly 75% going to land set aside.

Note: reductions in government payments of over 100 percent imply that the sign of net transfers is reversed.