Valuing environmental externalities associated with oasis farming in Alxa, China

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Abstract

The size of agriculture's environmental footprint is increasing due to the over-exploitation of surface waters and aquifers. This study investigated physical measurements of environmental externalities for maize cropping in oasis farming, north-western China, and the monetary value of these environmental externalities, based on integrated process-based biophysical and economic modelling. The results showed that current farming practices have caused 7854 Yuan/ha of recharge groundwater cost, 7696 Yuan/ha of water treatment cost and 91 Yuan/ha of nitrous oxide mitigation cost. Although the farmer's benefit cost ratio was 1.85, the social benefit cost ratio was only 0.55. A combination of farmers' adopting optimum practices and an increase in the water price to 1.1 Yuan/m^3 could maintain both the social benefit-and farmer benefit-cost ratios above 1.

Key Words

Environmental externalities, monetary valuation, oasis farming, integrated modeling, water pricing

Introduction

Recently, scientific findings have alerted the world to the increasing size of agriculture's environmental footprint. Unintended external effects, called environmental externalities, are side-effects of the economic activity and their costs are not paid for by farmers. Environmental externalities distort the market by encouraging activities that are costly to society, even if the farmer's benefits are substantial.

Valuation of environmental externalities is helpful in recognising their significance in agriculture and provides information for decision-makers to address these externalities. A few studies have been conducted on the environmental external costs of agriculture in the European countries and the USA (Lv *et al*., 2009), and recently, Lv *et al*. (2009) valued the environmental externalities associated with rice–wheat farming in south China. Because there are no standard frameworks and methods for assessment, the results of these different studies cannot easily be compared (Pretty *et al*., 2000). Most of these studies were either based on field-scale experimental results or statistical data.

A number of shortcomings need to be addressed if the field-scale experimental results or statistical data are employed. There noted are expressing individual farmers' behaviour using aggregated statistics and not reflecting the interactive relationships between environmental external effects and between the economic activity and environmental externalities. Modelling appears an ideal approach to understand farmers' behaviour and how farmers practices influence an agro-ecosystem. A process-based simulation model which describes in sufficient detail the dynamics of an agro-ecosystem is the most important element of the sort of modelling.

Eighteen percent of the arable land in China originates from the cultivation of grassland. Next to overgrazing, conversion to crop land, called 'oasis farming', has been the second major reason for increasingly serious grassland degradation. Alxa League, located in the north-western China, is recognised as one of the areas most seriously degraded in China. The average annual precipitation is 116 mm and potential evaporation is 20 times more than annual precipitation. There are about 20,000 ha of irrigated cropping based on 10 groundwater oases. A single season maize crop is predominantly grown because of its high yield. Due to the light texture of the soils excessive irrigation and fertiliser use result in substantial water loss through deep drainage and high concentrations of nitrate, ranging from 20 to 137 mg N/L, in groundwater.

The aim of this study was (i) to characterize the negative environmental externalities associated with maize cropping in oasis farming in Alxa; (ii) to estimate the monetary value of these negative environmental externalities; and (iii) to investigate effective policies to lessen these external costs.

Methods

Case study area

Left Banner in Alxa was chosen to represent the physical and socio-economic conditions for maize cropping in oasis farming of north-western China. Left Banner is located in the west of Alxa (37°24' -41°52' N and 103°21' -106°51' E). The soils are alluvial mixed with gray desert soils. Their physical properties are shown in Table 1. Maize cropping accounts for 70% of the oasis farming. Groundwater is the single source of irrigation water.

Table 1. Soil physical properties in Left Banner.

County	Soil layer (cm)	Particle fraction (%)			Texture (USDA)	pH	SOM (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)
		Sand	Silt	Clay						
Left Banner	0-30	31.4	66.5	2.1	Silt loam	8.6	1.19	0.08	0.18	21.4

Note: SOM, TN, TP, TK stand for soil organic matter, total nitrogen, phosphorus and potassium, respectively.

Physical dimension measurement of the environmental externalities

In terms of the main consequences of intensive maize cropping in oasis farming, we focused on three environmental externalities: groundwater depletion, groundwater pollution related to nitrate leaching, and nitrous oxide (N_2O) emission.

The physical dimensions of environmental externalities were simulated by process-based biophysical modelling (Li *et al*., 2007). The model simulated the key processes of crop growth within the water and nitrogen cycles. The inputs to the model were information on the climate (air temperature, relative humidity, solar radiation and wind speed), geography (latitude, average air CO_2 concentration) and crop biological parameters (biomass-energy ratio, harvest index) and agricultural management practices (crop rotation, irrigation, fertilisation, harvest and tillage). Its outputs were biomass, crop yield, evaporation, drainage, crop nitrogen uptake, ammonia, nitrate leaching and N_2O emission. This model was developed in Fengqiu County, North China Plain and applied in Left Banner (Hu *et al*., 2008). As Left banner is located in the middle of a desert area, it is assumed that there is no lateral groundwater recharge to the oasis. In addition, more than 90% of 116 mm precipitation falls during the growing season of maize. Therefore, groundwater depletion is calculated as the difference between irrigation applied and drainage during the growth period of maize. Nitrate leaching was obtained from modelling. When the nitrate concentration in drainage meets the water quality standard of 10 mg N/L, groundwater pollution related to nitrate leaching is considered to be zero. N_2O emission was directly obtained from the modelling.

Monetary evaluation of the environmental externalities

The restoration cost approach was used to assess the value of environmental externalities from the cropping system. This approach does not actually value the externality, but uses as a proxy the expenditure which society incurs in dealing with that negative externality. A carbon (C) tax has been frequently used in evaluating the economic loss caused by C emissions. We adopted the average rate of 142.5 Yuan/t of CO_2 and calculated the cost of N_2O emissions by multiplying the simulated emission amount by 310, the global warming potential of N_2O relative to CO_2.

When the nitrate concentration in drainage meets the water quality standard, groundwater treatment cost is zero. An average wastewater treatment cost of 1.6 Yuan/m^3 was adopted in this study. There are three methods available for the restoration of groundwater subject to over-exploitation: water diversion, recharging with treated wastewater, and arranging a protected area of groundwater recharge. The cost of recharging groundwater of 1.15 Yuan/m^3 was adopted, as obtained in consultation with local water resource experts, which comprehensively reflects the cost of all the above technologies and their potential application.

Simulation and evaluation of policies to avoid environmental externalities

The integrated biophysical-economic model was used to simulate the effect of different policies on the environmental externalities. The economic component was a simple farm gross margin analysis. A meta-model was used to link the biophysical model with the economic model. Crop yield was the key link between the two models. Wei *et al*. (2009a) developed the integrated economic-modelling in Fengqiu County, North China and Wei *et al.* (2009b) applied the model in Left Banner.

The potential role of provision of training and extension services was investigated as a policy measure. The maximum potential these services could provide was defined as the situation where farmers adopt the optimum practices. The optimum practices are considered to be the cases when farmers obtain the maximum yield and input resources are used most efficiently, which happens when farmers have all the knowledge needed for their farming activities. Then water pricing was investigated. The water price was increased from the present 0.1 to 2.0 Yuan/m^3 in incremental steps of 0.1. The benefit-cost analysis, as the policy analysis assessment tool, was conducted on both the society and farmers. The social benefit was specified as the crop output. The farmer benefit was the social benefit plus the subsidies from the government minus taxes, if they existed. The farmer cost was specified as the sum of irrigation cost, fertilizer cost, all other variable cost and all taxes (for details, see Wei *et al*., 2009a). Social cost was specified as the farmer cost minus the taxes plus the groundwater over-exploitation cost, groundwater treatment cost, and N_2O mitigation cost.

Results

With current practices, there is substantial groundwater depletion and the amount of nitrate leached is more than the applied nitrogen (Table 2). These physical environmental externalities, expressed in monetary terms, represent 7854 Yuan/ha for the cost of recharge groundwater, 7686 Yuan/ha for water treatment cost, and a much smaller cost for N_2O mitigation (Table 3). From the perspective of farmers, the current farming activities are viable. However, the social benefit cost ratio is only 0.55, so that these farming activities are not sustainable from the viewpoint of the society.

Table 2. Physical measures of the environmental externalities.

Practices	Irrigation applied (mm/ha)	Irrigation times	Nitrogen applied (kgN/ha)	Nitrogen application times	Yield (kg/ha)	Groundwater depletion (mm/ha)	Nitrate leached (kg N/ha)	N_2O emission (kg N/ha)
Current practices	1164	6	320	3	11606	683	436	2.1
Optimum practices	967	9	0	0	14213	837	71	0.35

Table 3. Economic measures of the environmental externalities.

Practices	Farmer's benefit cost ratio	Social benefit cost ratio	Recharge groundwater cost (Yuan/ha)	Water treatment cost (Yuan/ha)	N_2O mitigation cost(Yuan/ha)
Current practices	1.85	0.55	7854	7696	91
Optimum practices	2.77	0.88	9625	2080	15

At optimum practices, when farmers decrease irrigation amounts, increase irrigation times for 6 to 9 and do not apply nitrogen, nitrate leaching will be reduced from 436 to 71 kg N/ha, while the crop yield will increase by 2607 kg/ha (Table 2). At the optimum practices, the water treatment cost will decrease from 7696 to 2080 Yuan/ha and N_2O mitigation cost will decrease by 76 Yuan/ha, although the groundwater depletion cost will increase by 22.5% due to the deceased drainage. The farmer's benefit cost ratio will improve from 1.85 to 2.77 while the social benefit cost ratio increased from 0.55 to 0.88 (Table 3). This is indeed a win-win scenario. However, from the perspective of the society, the social benefit cost ratio should be at least 1, so further policy incentives are needed.

The effect of water pricing as a policy measure was simulated by the integrated economic-biophysical model (Figure 1). When the water price is increased to 1.1 Yuan/m^3 both the social and farmer benefit cost ratio would be larger than 1. That means the farming activities are feasible from the perspective of both the society and farmers. However, under this condition, the groundwater recharge cost is still very large at 8556 Yuan/ha (Table 4). Figure 1 also shows that only a small improvement in the social benefit cost ratio results from a substantial decrease in the farmer's benefit cost ratio, demonstrating that water price is very inelastic for the social benefit cost ratio.

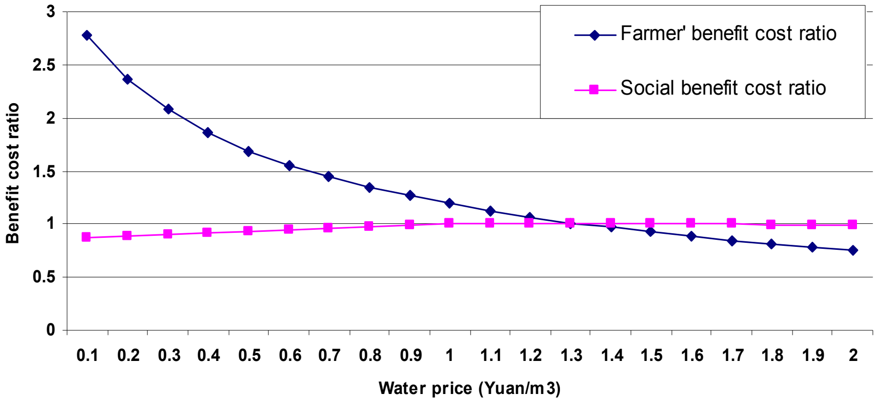

Figure 1. Effect of water price increases on farmer's benefit cost ratio and social benefit cost ratio.

Table 4. Physical measures and monetary measures of environmental externalities when both the social and farmer' benefit cost ratio are lager than 1.

Water price (Yuan/ m^3)	Crop yield (kg/ha)	Ground water depletion (mm/ha)	Nitrate leached (kg N/ha)	N_2O emission (kg N/ha)	Recharge ground water cost (Yuan/ha)	Water treatment cost (Yuan/ha)	N_2O mitigation cost (Yuan/ha)	Farmer benefit cost ratio	Social benefit cost ratio
1.1	13689	744	12.3	0.35	8556	416	15.46	1.13	1.002

Discussion and conclusions

This study investigated an approach for estimating the physical measures of environmental externalities associated with maize cropping in oasis farming of north-western China, and the monetary valuation of these externalities based on an integrated process-based biophysical and economic model. However imperfect and incomplete, the results from this study do help decision-makers to understand what the status of current farming activities is, what the environmental externalities are, how much they cost the society, and what the potential policy solutions to lessen these externalities are. It should be noted that the implementation of the recommended policy options would undoubtedly take time.

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