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Jointness in production and farmers' willingness to supply non-marketed ecosystem services

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ABSTRACT

This paper highlights how farmers' willingness to supply non-marketed ecosystem services (ES) is influenced by whether or not the non-marketed ES are produced jointly with agricultural products. When marketed products and non-marketed ES share some production inputs the production relationships between the two may be complementary, competitive or substitutive. Using a cost minimization framework, it is shown how complementary relationships lead to costless voluntary provision of non-marketed ES (typically the case for ES that are supportive of provisioning ES for marketed farm products). It is also shown how competitive production relationships lead to provision of non-marketed ES at lower cost than when non-marketed ES are direct substitutes for farm products or are produced outside of agriculture. The paper closes by showing how the minimum willingness to accept (WTA) payment for ES that are complementary/competitive is less than or equal to the minimum WTA for the same ES produced in substitute or independent production relationships.

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1. Introduction

Human society receives goods and services from ecosystems that vary along the spectrum from natural to managed ecosystems (Tilman et al., 2002). Agro-ecosystems are arguably the most important managed ecosystems in the world; together, cropland, pasture and rangeland are estimated to cover some 40% of the Earth's land area (Foley et al., 2005). Although the primary role of agro-ecosystems is to produce food, fiber and fuel, many other benefits are important that are difficult to quantify and have rarely been priced. As a first classification of the various goods and services provided by these managed ecosystems, a useful distinction is that into 'provisioning services', 'regulation services' and 'cultural services' (de Groot et al., 2002; Millennium Ecosystem Assessment, 2005). Regulation services result from the capacity of (agro)ecosystems to regulate climate, hydrological and biochemical cycles, earth surface processes, and a variety of biological processes. Cultural, or information, services relate to the benefits from (agro)ecosystems through recreation, cognitive development, relaxation, and spiritual reflection (see Hein et al., 2005 and references therein). In this paper, we denote these provisioning, regulation and cultural/information services as ecosystem service (ES), and we focus on those linked to agriculture.

In addition to the three categories of ES above, the fourth category of 'supporting services' represents the web of supporting biotic and abiotic processes that underlie the functioning of the agro-ecosystem (de Groot et al., 2002). Supporting services include soil formation, crop pollination, natural pest control, and nutrient and water cycling. We show that because the supporting services are instrumental to the

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Table 1 – Indicative classification of production relationships between selected ES and marketed crop products

Ecosystem service	Relationship to crop production
Supporting ES	
Soil formation and retention	Complementary/competitive
Pest control (relying on non-crop habitat)	Complementary/competitive
Pollination (relying on non-crop habitat)	Complementary/competitive
Regulating ES	
Biodiversity (non-pest, non-crop)	Substitute
Cultural and information ES	
Aesthetic landscapes	Competitive
Nature recreation	Substitute

functioning of the agro-ecosystem, they have dual roles. They serve as inputs to marketed provisioning services (e.g., food, fiber, fuel) and also as outputs of agro-ecosystem management that are complementary to provisioning ES. This paper explores the output role, both for supporting ES and for other ES outputs from agriculture that are not complementary in production. We limit our assessment to anthropocentrically defined ES (Boyd and Banzhaf, 2006, p. 8; Kremen, 2005, p. 468; Millennium Ecosystem Assessment, 2005).

The fundamental reason ES are interesting from an economic perspective is that markets have problems handling efficiently the provision of ES because many ES are externalities and public goods. ES from agriculture are an important and unique case. Markets do exist for many of the provisioning ES from agriculture: food, fiber and fuel. Likewise, indirect markets exist for some supporting ES that supply agricultural inputs, such as atmospheric nitrogen fixation. But markets are missing or incomplete for many ES from agro-ecosystems, such as (i) regulation of water quality and quantity, of climate and of biotic community structure, (ii) cultural ES embodied in a scenic farm landscape, (iii) recreational fishing and hunting, and (iv) protection of charismatic wild species appreciated by sightseers. The range of market involvement in provision of ES from agriculture is the first reason that agriculture offers special opportunities for ES management.

The second reason that agriculture offers special opportunities for ES management is that many are produced simultaneously with agricultural products (Table 1). Society increasingly values the non-marketed ES (NMES) from agriculture, and it is increasingly clear that farmers can produce them as well as food, fiber and fuel (Cochrane, 2003). Without any policies to associate a positive price with NMES, their supply is determined by the incentives to supply marketed crops and livestock (Antle and Valdivia, 2006). However, because of the range of market exposure by agriculturally produced ES and because some NMES are produced jointly with agricultural goods, ES provision by agriculture does not neatly fit the standard wisdom that NMES will fail to be produced.

This paper discusses how micro-economic principles such as economies of scope, joint products and opportunity costs can provide insights into the willingness of farmers to supply ES and the corresponding costs to them of doing so. It explores the costs of alternative ways to mix agricultural and ES outputs in order to assess the cost of producing more ES.

The paper proceeds as follows. In the context of market-based agricultural production, it first distinguishes between supporting ES that complement agricultural production and other types of ES (notably regulating and cultural NMES) that are non-marketed externalities. It proceeds to develop a multiple product model of agriculture that produces both marketed farm products and non-marketed ES externalities. The paper explores the costs of providing several categories of NMES through agriculture versus by non-agricultural means, according to the degree of jointness of those products with agricultural products. It examines how jointness of agricultural and ES production affects potential farmer willingness-to-accept payment to produce NMES. The paper concludes with recommendations for policy-relevant research to capitalize on the special characteristics of agriculture for provision of NMES.

2. Ecosystem services from agriculture and joint production

Farmers earn their livelihoods from producing and selling agricultural products. The management decisions they make regarding land and other agricultural inputs both affect and are affected by the biophysical and economic settings where they operate. Physical yields of marketable commodity outputs and ES of agricultural production systems are influenced by abiotic and biotic factors that are highly specific to particular locations. Relevant site characteristics include: soil factors such as organic matter, texture and sediment profile; climatic factors such as solar radiation, precipitation and temperature; biotic factors such as the naturally occurring communities of flora and fauna; and economic infrastructure, such as roads, input suppliers and markets. Management history is also site specific and includes factors such as the origin of the land and past management, presence of vegetation remnants and extent of the plant seed bank. The site characteristics, management history, economic infrastructure and climate are beyond farmers' control and together determine the abiotic and biotic setting of a specific farm site.

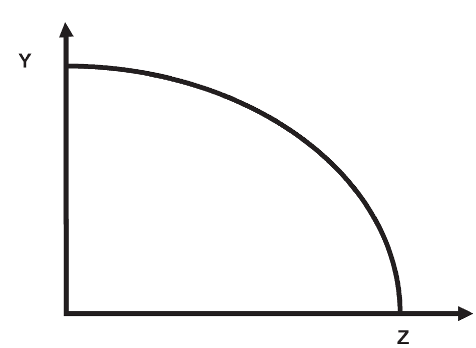

Fig. 1 – Production possibilities frontier (PPF) for marketed agricultural product *Y* and ecosystem service *Z* as competitive products.

Farmers exert considerable control over other biological, chemical and physical processes of the agro-ecosystem. They particularly focus on managing factors that affect crop or livestock growth and the yield of marketable farm products. Farmers apply inputs to complement and supplement the natural, supporting ES in order to ensure that crops and livestock grow rapidly (nutritional inputs), healthily (pest management inputs), and produce abundant, high-quality yields (genetic and reproductive inputs). The type and level of input use and outputs generated affects the characteristics and the significance of environmentally critical processes (water balance, regulation of erosion and sedimentation, breakdown of pollution, pollination and the nitrogen cycle). ES from agriculture result from the interaction of the crop growth limiting and reducing factors, the crop growth and yield-enhancing ecosystem functions, the availability of manufactured inputs and the biotic and abiotic factors that are beyond the farmer's control (cf. de Koeijer et al., 1999; Wossink et al., 2001).

The NMES associated with agriculture fall into two categories, according to the market incentives that they offer to farmers. Certain NMES provide intermediate products in the agricultural production process that have market value because they contribute directly to output of marketable farm products (Beattie et al., 1974; Swinton and Zhang, 2005). This category includes NMES such as soil nitrogen fixation, soil aeration, pollination by wild pollinators, and pest control by natural enemies. Most of these essential services have parallel input markets, and they have monetary value to farmers that can be calculated from the marketed input replacement cost or value of productivity changes (Barbier, 2000; Shiferaw et al., 2005). Other NMES have no market value to farmers, so if they are produced, it is because of farmers' personal preferences or simply as accidental byproducts or externalities. This latter category includes regulatory ES like water quality (which could be a beneficial ES or a harmful disservice, in the instance of water pollution), landscape appearance, net carbon sequestration, or wildlife habitat provision.

The concept of joint production allows the translation of the insights summarized above into economic terms. The production of marketed products and NMES can be viewed as a joint production process. Joint provision implies a technical interdependency: this interlinking is such that (some) inputs cannot be assigned to either of the two outputs (Shumway et al., 1984). The most fundamental property of technical interdependencies is that a change in the supply of one output (over some range) simultaneously affects the output of the second output. Consider a marketed product, Y, and a NMES, Z. The classic model for production of multiple products admits two principal potential product–product relationships: competitive and complementary.[1] Competitive products involve a trade-off such that more of one cannot be produced without less of the other. This is illustrated by the decreasingly concave production possibilities frontier (PPF) as in Fig. 1. Complementary products can be produced in increasing quantities, as in the increasing interval (Y_0, 0, Y_{max}, Z_0) of the PPF in Fig. 2.

[1] Supplementary products are an intermediate special case subsumed in the other two.

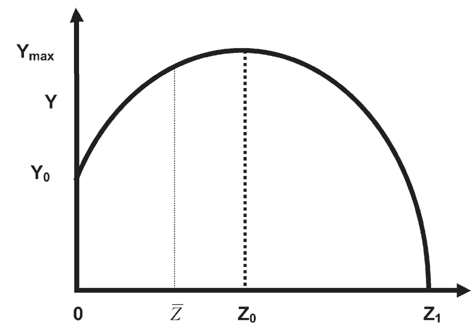

Fig. 2 – PPF for marketed agricultural product *Y* and ecosystem service *Z* as complementary products over interval 0,Z_0.

Jointness in functional terms and complementarity or competitiveness in terms of the production possibility set need not be incompatible. Frequently, the joint production of agricultural outputs and ES is characterized as having a complementary–competing production possibility frontier, meaning that when one of the outputs (say Y) is receiving low levels of the shared input, the two outputs are complementary but that at higher levels of Y they become competitive (Gatto and Merlo, 1999; Hodge, 2000, p. 265; Romstad et al., 2000, p. 24; Havlík et al., 2005, p. 494). Fig. 2 illustrates this relationship.

Jointness in production comes from either technical interdependencies or the presence of "non-allocatable" inputs that cannot be separately managed between products (see Romstad et al., 2000, p.15 and Nilsson, 2004, pp. 31–34). For example, nitrogen fertilizer cannot be allocated separately between what is taken up by plant roots to enhance crop growth and what volatilizes into nitrous oxide, a greenhouse gas. Much research in agricultural economics has focused on allocation of inputs among products for which there are established markets. In general, a farmer who chooses to produce Z on part of his or her land does so because of a "composite" Y–Z activity or technical interdependence where Y benefits (see Boisvert, 2001, pp. 118–119; Nilsson, 2004, p. 32). An example would be the case of competing land uses for production of crop Y versus habitat for an ecological community that provides pest predation or crop pollination services, Z, to the crop. Without the crop Y benefiting from Z, the farmer would not be interested in producing Z.

Good agricultural practice will dedicate land, and other fixed and also variable inputs, to maintain a resource base that ensures sustainable management in the long run, including those resources necessary to maintain those NMES that provide intermediate products supporting production of Y. Because Z is assumed to have no market, its price without government intervention will be nil, so agricultural product Y is produced at its maximum. In Fig. 2, the maximum for Y corresponds to level Z_0 of the unpriced NMES.[2] This outcome

[2] In a following section, we develop a price for Z and show how that can be used to induce farmers to supply Z at socially optimal levels.

corresponds to cases like pollinator habitat, where farmers are observed to set aside land that could be planted in order to protect habitat that increases their crop production. Many other examples can be given, such as dedicating land and variable inputs to conservation buffers and the cultivation of cover crops for the sake of erosion control and soil fertility enhancement.

In Fig. 2, the curve may be regarded as an agro-ecosystem services production possibilities frontier. It represents the maximum attainable flow of NMES for any level of agricultural output.

3. Economics of producing multiple products or services

That Y and Z are joint products does not necessarily mean that they must be produced in fixed proportions. Alternative production technologies typically permit Z and Y to be produced in different proportions, depending on both the production technique and the inputs chosen. For a profit-maximizing producer, the optimal choice of product mix depends on the direct costs of production as well as the opportunity cost of not producing more of the joint product. Consider a production function, $F(X,Y,Z;D)$, that describes how marketed output Y and NMES Z are jointly produced in a specific biotic and abiotic environment D using an input, X, like land, that affects output of both Y and Z. The problem for the profit-maximizing producer is to find the most profitable mix of products, given a cost function that depends on output levels and input X, at variable cost w per unit.

$$\max_{Y,Z} \pi = p_Y Y + p_Z Z - C(w,Y,Z)$$

$$\text{s.t.} \quad F(X,Y,Z;D) \geq 0 \tag{1}$$

Because Z is not marketed, p_Z is 0, so the only opportunity cost is the cost of not producing more of marketed good Y. Profit-maximizing behavior implies ignoring Z and focusing on optimal output of Y. Building on the complementary–

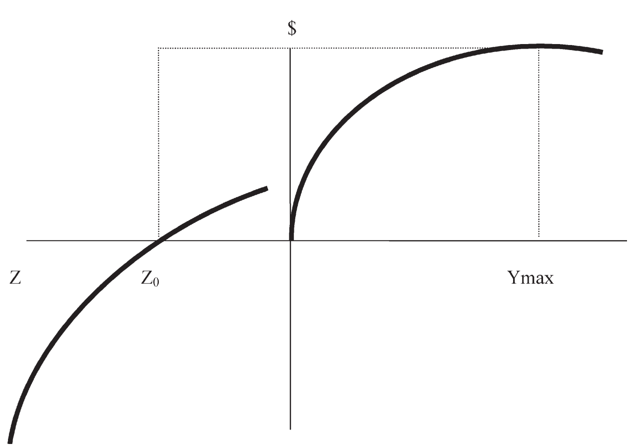

Fig. 3 – Opportunity cost curve for unpriced ecosystem service *Z* (left side) is less than 0 in complementary production relationship with profit frontier of marketed agricultural product *Y* (right side).

competitive example illustrated in Fig. 2, the idea of opportunity cost under complementary production conditions is illustrated in Fig. 3. In its top right quadrant, Fig. 3 shows the profit frontier for Y, including the maximum profit that can be achieved using the various technologies on the PPF (for a more detailed discussion, see Russell, 1993). Transforming the resulting relationship into Z space in the left half of Fig. 3 illustrates the opportunity cost in terms of forgone Y sales of moving rightward along the PPF in Fig. 2 and allocating less land to Y than is needed to achieve Y_{max}. The opportunity cost of producing Z may be interpreted as the minimum that a farmer would be willing to accept (WTA) for providing a NMES. It follows that for ecosystem services up to level Z_0, the producer incurs no loss in profit. Thus, up to Z_0, the producer's WTA would be less than or equal to 0 because NMES contributes to agricultural production in that interval.[3]

To extend the analysis of economic trade-offs between NMES and marketed farm outputs, we turn to a cost minimization framework. Cost-minimization allows us to look explicitly at the cost of providing NMES Z at a specified level $\bar{Z}$, which can be imagined to have been imposed by a benevolent social planner. Likewise, we also assume that marketed good Y must be provided at some minimum level, $\bar{Y}$. Assuming a quasi-convex cost function, the problem can be stated as follows:

$$\begin{aligned} &\min_X \; C(Y,Z,w) = wX \\ &\text{s.t.} \quad F(X,Y,Z;D) \geq \bar{Y} \\ &\qquad\;\; F(X,Y,Z;D) \geq \bar{Z} \end{aligned} \tag{2}$$

This constrained optimization problem can be reformulated as an unconstrained Lagrangian function and differentiated to obtain three first-order conditions for an optimal solution:

$$-w + \lambda_1 F_{Y(X)} + \lambda_2 F_{Z(X)} = 0 \tag{3}$$

$$F(X,Y,Z;D) - \bar{Y} = 0 \tag{4}$$

$$F(X,Y,Z;D) - \bar{Z} = 0 \tag{5}$$

where λ_1 and λ_2 are the Lagrange multipliers for the minimum constraints on marketed output Y and NMES Z in Eq. (2). In Eq. (3), the marginal effect of input use on output of commodity Y, $F_{Y(X)}$, is composed as follows:

$$F_{Y(X)} = \frac{dF}{dX} = \frac{\partial F}{\partial Y}\frac{\partial Y}{\partial X} + \frac{\partial F}{\partial Y}\frac{\partial Y}{\partial Z}\frac{\partial Z}{\partial X} \tag{6}$$

where $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial X}$ denotes the direct effect of input X and $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial Z}\frac{\partial Z}{\partial X}$ denotes the indirect effect of X on Y by way of ecosystem

[3] Note that where agricultural policy supports prices, the WTA for ES supply will be inflated, because foregone revenue will be larger than under free market conditions. Hence, in order to analyze payment for ecosystem services as an alternative to agricultural price support policies, the WTA value should be based on the free market price of Y. In addition, to qualify for the "green box" of the World Trade Organization's (WTO) Agreement on agriculture, a subsidy payment must not distort trade. This means that the subsidy has to be government-funded and must not involve price support (Josling, 2005).

service Z. Input X contributes to both agricultural output and ecosystem services, so $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial X}\geq 0$ and $\frac{\partial F}{\partial Z}\frac{\partial Z}{\partial X}\geq 0$. Based on the discussion in Section 2, we assume that Z becomes an inferior input for the production of the commodity output once a specific level Z_0 of NMES has been reached. Thus $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial Z}\geq 0$ for $Z\leq Z_0$ and $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial Z}\frac{\partial Z}{\partial X}<0$ for $Z>Z_0$.

Under the assumption that the production function F(.) is sufficiently well behaved that the second-order conditions for a constrained minimum are satisfied, the solutions of the first-order conditions yield the indirect cost function:

$$C^*(X,\overline{Y},\overline{Z}) = wX^* \tag{7}$$

We are particularly interested in how this minimum cost function will respond to a change in the minimal acceptable level of ecosystems services, $\frac{\partial C^*}{\partial \overline{Z}}$. Using the envelope theorem and the first-order conditions above, this shadow price can be formulated as:

$$\frac{\partial C^*}{\partial \overline{Z}} = \lambda_2^* = \frac{w-\lambda_1^* F_Y(x^*)}{F_Z(x^*)} \tag{8}$$

Eq. (8) shows how the generation of NMES and agricultural production are connected through technical interdependencies and non-allocatable inputs. When the optimal amount of input X^* yields insufficient NMES to satisfy $\overline{Z}$, a rearrangement in input use, ∂X^*, is required to generate more NMES, see Eq. (5). This rearrangement in input use, ∂X^*, affects output Y, see Eq. (6). We can now distinguish two major cases depending on $\overline{Z}$, the imposed minimum acceptable level of ecosystem services:

- *Case 1:* For $0\leq\overline{Z}\leq Z_0$ (for Z_0 see Fig. 2), the sum of the direct yield effect, $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial X}$, and the indirect yield effect, $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial Z}\frac{\partial Z}{\partial X}$ of input use is positive (but decreasing) and the farmer can produce more Z while also increasing his commodity output Y. In this situation, the shadow price of the constraint on ES is nil, $\lambda_2^*=0$.

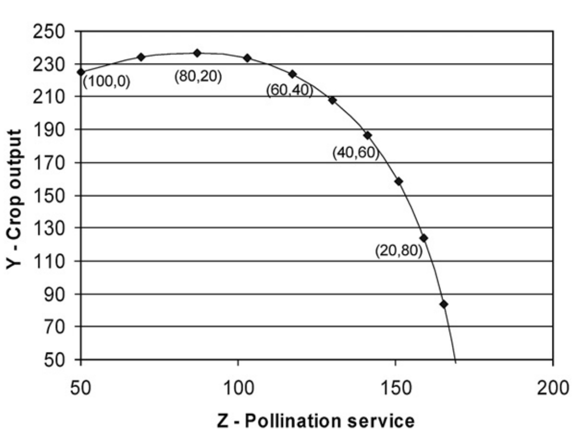

Fig. 4 – Illustrative complementary–competitive production frontier (results are generated by the equations: $Z=50+2X-0.008X^2$ and $Y=20+5X-0.03X^2+0.1Z$) for crop (Y) and pollination services (Z) with dedicated land shares varying (percentages to Y and Z in parentheses).

- *Case 2*: When $\overline{Z}>Z_0$ further reallocation of inputs X is not possible without a net loss in yield. The direct yield effect of reallocating X is not nil and there are yield losses caused by the required increase in Z needed to satisfy the constraint on the ecosystem services, $\overline{Z}$. In this case, there is a shadow price of the constraint on ES, $\lambda_2>0$, made up of the expenditures for the additional inputs X and the net loss in yield.

These two cases are illustrated in Fig. 4, which shows simulated outcomes for ten allocations of land (X) between a hypothetical crop (Y) and an NMES-like pollination (Z) whose contribution to crop productivity rises with increased nearby pollinator habitat. Hence, the underlying equation for Y is increasing in Z (see footnote to Fig. 4). This indicative illustration shows how due to rising crop yields, land can be shifted from cropland to pollinator habitat with increases in both outputs up to the point Z_0 where 20% of the land is in pollinator habitat.

Both the farmer and the policymaker can be expected to be interested in partially joint production relationships, because these relationships affect the degree of compensation that a farmer would require to cover the full costs of providing some socially desirable level of NMES. Over the range $0\leq\overline{Z}\leq Z_0$, increase in ES incurs no cost to the farmer, so should require no compensation. Over the range $\overline{Z}>Z_0$, compensation would be require to produce level $\overline{Z}$ of NMES, but the cost would be less than for producing $\overline{Z}$ in the absence of a marketed joint product like Y.

The production function for non-marketed ecosystem service Z is subject to at least two sources of farm and farmer heterogeneity. First, it depends upon the site-specific physical environment and the specific crop produced as reflected in the production function F. Hence, it will vary across space with the site-specific environmental parameter *D*. Antle and Valdivia (2006) have shown how spatial heterogeneity can generate a supply curve based on differential costs of providing ecosystem services through both site costs and transaction costs. Second, aversion to risk may affect farmers' willingness to change to increase provision of socially desirable NMES (Kurkalova et al., 2006).

The two cases described above particularly apply to ES that are supporting of agricultural production over a certain range of input allocation, which can be described by a complementary–competitive PPF as in Fig. 2. Examples would be dedicating land to habitat for pollination and pest predators or to cover crops and terraces that aid in soil formation and retention (Table 1). By contrast, for NMES that are perfect substitutes in production for agricultural commodities, the PPF would be linear so only Case 2 would apply. An example would be production of wetland ES versus draining the land for agriculture (Table 1).

4. WTA and economies of scope

The class of production relationships that are complementary–competitive fits the general definition of economies of scope, which occur when the minimized cost of production of two or more products jointly is less than the sum of the costs of producing each product individually (Willig, 1979). The previous section shows that whenever the production relationship between a farm product Y and ecosystem service Z shows some opportunity for economies of scope, the joint production of Y and Z will be cheaper than production of Z separately. Consider the situation where ecosystem services, Z, are produced by a non-farmer whose production process lacks the opportunity for complementary production of a marketed product. In this case, the first constraint of Eq. (2) will not be present in the cost minimization problem and the term $-\overset{*}{\lambda}_1 F_{Y(\overset{*}{X})}$ disappears from Eq. (8). Thus, without agricultural production, the marginal cost of producing ES is always positive. This is illustrated in Fig. 5 where $C'(Y,Z)$ is the marginal cost curve for the farmer and $C'(Z)$ is the marginal cost curve for a non-farmer who both provide the same NMES. The curve $C'(Y,Z)$ will be more steeply sloping than curve $C'(Z)$ because of the yield loss caused by ES production; $\frac{\partial F}{\partial Y}\frac{\partial Y}{\partial Z}<0$ for $Z>Z_0$. At a certain level of ES production, Z_1, agricultural production will no longer be possible and the cost of producing one extra unit of Z by a farmer and non-farmer become identical: $C'(Y,Z)=C'(Z)$.

With total cost given by the area under the marginal cost curve, it follows that production of ES by the farmer is always less expensive: $C(Y,Z)\leq C(Z)$. For the given level of ecosystem services, $\bar{Z}$, the cost for the non-farmer would be $OA\bar{Z}$ whereas the cost for the farmer would be $OB\bar{Z}$.

An individual's minimum willingness to accept (WTA) payment for changing the level of NMES provided represents a supply-side measure of NMES value. Of course, such values are specific to the production setting, and they are valid only for the specific *incremental* changes of NMES provision evaluated. Moreover, such values ignore the demand for NMES that may exist separately from the production process. If the marginal cost of providing a NMES can be estimated from the combined marginal resource cost and the marginal opportunity cost of reduced output of marketed product (as in Eq. (8) above), then an individual's WTA to produce NMES by a given technology is the area under the marginal cost curve, as in Fig. 5.

The social cost of attaining a desired level of NMES by relying on farmers has the potential to be lower when Z is a partially joint product of agricultural management, as also illustrated in Fig. 5 (see Freeman, 1991; also Barbier, 2000). Assume that the socially desirable level of ecosystems services as imposed by regulation for a given piece of land is $\bar{Z}$. In addition, assume that both the farmer and the non-farmer would be compensated based on their WTA curve. The reduction in social cost from switching to the joint production of Y and Z is equal to the area between the two cost curves up to level $\bar{Z}$, area $OABZ_0$ in Fig. 5.

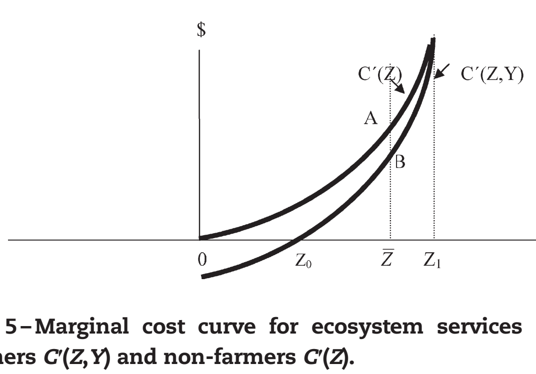

Fig. 5 – Marginal cost curve for ecosystem services *Z* for farmers *C′*(*Z*,*Y*) and non-farmers *C′*(*Z*).

5. Policy implications

Three policy implications arise from the analytical framework presented here. First, when agriculture generates NMES and commodity outputs as joint products, these need to be addressed simultaneously for policies to be efficient. Depending upon the nature of the production process, there may exist win–win opportunities for costless provision of NMES when those services are complementary to agricultural commodity production.

Second, there is no general justification for subsidizing agricultural production for the sake of increasing output of NMES. Instead the incentive should be achieved through a payment linked to the NMES provision. Of course, if current agricultural production relies on subsidies and also generates NMES as joint products, then a sharp reduction in agricultural subsidies could dramatically reduce the provision of NMES (cf. Glebe, 2007).

Third, although the model presented here abstracts from spatial heterogeneity, in fact the supply of NMES depends on the spatial distribution of the opportunity costs of providing these services as determined by the biotic and abiotic environment (represented by *D* in Eq. (1)) and market conditions (Antle and Valdivia, 2006; Lant et al., 2005). Thus, optimal policy prescriptions are likely to be highly location-specific due to the heterogeneity in both in site-productivity and of NMES and in demand for these services.

6. Concluding remarks

This paper has highlighted how farmers' willingness to accept payment for provision of non-market ecosystem services is influenced by whether or not the NMES are produced jointly with agricultural products. When marketed products and NMES share some production inputs (notably land), the production relationships between the two may be complementary, competitive or substitutive. Using a cost minimization framework in which the producer has no preference for the NMES in question, we showed how complementary relationships lead to costless voluntary provision of NMES (typically the case for ES that are supportive of provisioning ES for marketed farm products). In addition, we showed how competitive production relationships lead to provision of NMES at lower cost than when NMES are direct substitutes for farm products or are produced outside of agriculture with no marketed complement and the same ES production technology. We closed by showing how WTA payment for NMES that are complementary–competitive are less than or equal to WTA for the same NMES produced in substitute or independent production relationships. These economies of scope make provision of NMES by farmers attractive from a policy perspective. To date, the extent of these economies of scope has been addressed by few empirical studies (Peerlings and Polman, 2004; Havlík et al., 2005). Studies that use the PPF approach in the context of commercial timber production and biodiversity include those of Lichtenstein et al. (2003) and Nalle et al. (2004).

The conceptual framework presented here should help to frame thinking about the value of NMES from agriculture. There exists a major agenda for research to estimate WTA values empirically for the wide variety of NMES that can be produced under agricultural management. As shown in Table 1, non-marketed ES from agro-ecosystems offer a range of relationships with marketed agricultural products. The model presented here highlights the special nature of NMES that can be produced as a partially joint product in an agricultural process.

Empirical evaluation should particularly explore the multiple product framework in the context of spatial heterogeneity. Spatial heterogeneity, the "where" issue, matters both economically and ecologically. Economically, spatial heterogeneity matters because the economic landscape of access to markets varies as much as the biophysical landscape. Both these spatial factors affect where changing production practices are most effective and least costly (selective control). Ecologically, spatial heterogeneity matters because the scale of ecosystem functioning at which NMES are provided may not match the scale at which agricultural management interventions are made. For example, activities to preserve the water balance and the nutrient cycle take place at the field level, but the associated services are generated at the regional scale. Underlying ecological relationships will also vary across regions and locations. This makes the spatial representation of the economic framework presented in this paper a critical feature.

The model has three important limitations that should be the subject of future research. First, the model is limited to a single ecosystem service and a single agricultural product. In fact, most agricultural production processes produce many joint ecosystem services and disservices. The phenomenon of multiple externalities constitutes an important challenge to preventing the double counting of services in the valuation of NMES (Barbier, 2000; Pagiola et al., 2002; Turner et al., 2003).

A second model limitation is that prices are exogenous. Boisvert (2001) has shown how government intervention to affect NMES price can shift the supply curve of a jointly produced agricultural product, implying a feedback loop changing λ_1 in Eq. (8). This will obviously not happen when non-farmers produce NMES. Empirical research into designing payments for environmental services will have to anticipate such feedback effects in order to obtain accurate estimates of farmer WTA payment for changes in production practices that increase NMES provision.

The third limitation is that this production possibilities frontier model is static and spatially homogeneous. In fact, heterogeneity in the biophysical environment and firm resource bases influences the shape of technical production relationships over space, and technological change and management can shape their evolution over time. The latter two factors can both be influenced by policy. Empirical research exploring temporal and spatial dynamics of trade-offs between marketed farm products and non-marketed soil conservation conducted by Lant et al. (2005) is an important step in this direction.

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