A Note on the Valuation of Ecosystem Services in Production

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Abstract

There has been considerable recent interest in the valuation of ecosystem services. We focus here on the value of such services in the production of market goods. Although the conceptual basis for conducting such exercises is straightforward, the data with which to implement them empirically is generally not available. An upper bound on the value of ecosystem services arises when the production technology exhibits constant returns to scale in ecosystem services and market inputs jointly. There are compelling reasons to suppose that the existence of fixed factors of production would imply that production technologies exhibit decreasing return to scale. Under these circumstances, no general conclusions can be drawn. We show in an illustrative example that a range of outcomes is possible, depending on the substitutability between ecosystem services and other inputs and the scarcity of ecosystem services relative to other factors of production.

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I. Introduction

There has been considerable recent interest in the economic value of ecosystem services. The subject has attracted attention from interdisciplinary groups of ecologists, economists, and others (for example, Daily 1997; Costanza and others 1997; Dasgupta, Levin, and Lubchenco 2000; Heal 2000; Daily and others 2000). Several authors have proposed lists of valuable ecosystem services. The following, adopted from Daily (1997), is representative:

- Purification of air and water

- Mitigation of floods and droughts

- Detoxification and decomposition of wastes

- Generation and renewal of soil and soil fertility

- Pollination of crops and natural vegetation

- Control of agricultural pests

- Dispersal of seeds and translocation of nutrients

- Maintenance of biodiversity

- Protection from the sun's harmful rays

- Partial stabilization of climate

- Moderation of temperature extremes and of the force of winds and waves

- Support of diverse human cultures

- Providing of aesthetic beauty and intellectual stimulation.

It would be heroic indeed to suppose that a price tag could be placed on such a varied and pervasive list of services. Efforts to do so have come under a great deal of criticism (Costanza and others 1997; for some samples of rejoinders, see Ayres, 1997; Smith 1997; Freeman, 1998; Toman 1998; and Pearce 1998). The difficulties are compounded if our objective is to go beyond the valuation of the service per se and to consider the value of the natural ecosystems providing the service.

Despite the difficulties involved, making decisions concerning policies that affect natural ecosystems and the services they provide society is unavoidable. Moreover, natural scientists warn that the actions humanity is collectively taking are profound, unprecedented, and quite possibly irreversible. We should, then, consider the values at stake in all earnestness.

Regrettably, we must start from a meager knowledge base. Economists have limited tools to apply to the valuation of goods and services that are not traded in markets. Very little work in ecology informs the type of marginal analysis on which economists typically rely in performing valuation exercises. In fact, there are very few places in the world in which there is any evidence as to the quantities of services ecosystems provide.

Given these circumstances, perhaps the best we can hope for is to make slow progress in learning the types of things that determine ecosystem service values. In this paper, we consider a specific type of problem, derive an upper bound on the value of ecosystem services, suggest some ways of determining whether actual values are likely to approach this upper bound, and conclude with an example that demonstrates the indeterminacy of results in general.

We will confine our attention to those services useful as inputs into the production of marketed commodities. They include water supply and purification, flood and drought moderation, pest control and pollination services, waste detoxification and disposal, and nutrient and seed dispersal. Cultural, aesthetic, and ethical considerations are excluded from consideration here,[1] as is the potential of diverse natural ecosystems as sources of new products.[2] The decision to exclude these other considerations is not intended to minimize their importance. Rather, our objective is to isolate phenomena in hopes of understanding them more clearly.

The economic prescription for valuing the contribution of an input into the production of a market output is deceptively simple: it is the value, at the market price, of the marginal product of the input in production. It is a powerful prediction when all inputs and outputs are traded in competitive markets but of limited use when one or more markets are missing, as they typically are for ecosystem services.

Production (or equivalently, cost or profit) functions could, in theory, be estimated as functions of quantities (or equivalently for cost or profit function estimation, prices) of market inputs and quantities of ecosystem services. As we have already mentioned, however, data on ecosystem services is so limited as to generally preclude such an approach (one of few exceptions is Acharya 2000).[3] Similarly, hedonic approaches are, by and large, conspicuous by their absence (exceptions include Geoghegan, Wainger, and Bockstael 1997 and Mahan, Polasky, and Adams 2000).

Given that data limitations preclude more sophisticated approaches, the only alternative may be to derive an upper bound on the value of ecosystem services by ascribing the excess of the value of production over payments for the acquisition of purchased inputs to ecosystem services (see Alexander and othersfor an example of this approach). The problem, of course, is that other scarce factors of production may also be commanding rents that cannot be separated from those accruing to

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[1] Estimates of intangible values come largely from "contingent valuation studies," which have themselves been the subject of considerable controversy (see Diamond and Hausman 1994, Hanemann 1994).

[2] The economic value of biodiversity for use in new product search has been estimated (with wildly different results) by Simpson, Sedjo, and Reid (1996) and by Rausser and Small (2000).

[3] It is revealing that econometricians have devoted considerable effort to obviating the need to collect ecosystem service data. Ecosystem services are examples of the types of unobservable information econometricians typically relegate to the "disturbance term" and then try either to eliminate by clever choice of functional form or for which they compensate by choice of instrumental variables.

ecosystem services. One way of checking whether this upper bound approach provides a reasonable estimate of value would be to determine whether earnings, as represented—for example, in property rental or sales prices—vary proportionately with quantities of ecosystem services received. However, data availability problems may again prevent the application of such an approach. Moreover, even when it seems reasonable to suppose that ecosystem service flows decline with distance from natural habitats, it may be impossible to decompose price changes into the negative effects of declining ecosystem service and the positive benefits of, for example, proximity to markets.

The upper bound approach we have suggested is equivalent to supposing that production processes exhibit constant returns to scale in purchased inputs and ecosystem services and that no other inputs are valuable in production. We show in a simple example that "anything can happen" when we relax this assumption. Particular outcomes depend on the scarcity of ecosystem services relative to other fixed factors and substitution possibilities between them.

II. The Value of Ecosystem Services in Production

Consider a production process in which output (q) depends on purchased inputs (x), ecosystem services (ϕ), and another fixed factor (k)—that is, $q = f(x, \phi, k)$.[4] Output sells for a price p, and inputs can be purchased for a price w. For concreteness, and because such examples are frequently discussed in the ecological literature, we might think of the "production process" being a farm at a certain location, served by a certain flow of ecosystem services.

Standard arguments establish that the effect on welfare of a change in the quantity in which ecosystem services are provided can be measured as the change in competitive profits in the industry affected. Let profit (π) be

$$\pi = pf(x, \phi, k) - wx \tag{1}$$

Differentiating totally with respect to ϕ, we have

$$\frac{d\pi}{d\phi} = (pf_x - w)\frac{dx}{d\phi} + p\frac{\partial f}{\partial \phi} = p\frac{\partial f}{\partial \phi} \tag{2}$$

because $pf_x - w = 0$ under the assumption that purchased inputs are employed optimally.

If x, ϕ, and k comprise literally all the factors of production, it is almost a tautology to say that the production technology must exhibit constant returns to scale in the three factors jointly.[5] Then

$$pq = p\frac{\partial f}{\partial x}x + p\frac{\partial f}{\partial \phi}\phi + p\frac{\partial f}{\partial k}k$$

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[4] All variables will be treated as scalars for simplicity, but the extension to higher dimensions is straightforward.

[5] There does not seem to be any compelling reason to suppose that increasing returns to scale would obtain in a situation in which we are implicitly supposing a fixed technology.

or

$$pq - wx = p\frac{\partial f}{\partial \phi}\phi + p\frac{\partial f}{\partial k}k \tag{3}$$

Thus,

$$\frac{d\pi/\pi}{d\phi/\phi} = 1 - \frac{p(\partial f/\partial k)k}{\pi} \tag{4}$$

If the fixed factor, k, is in excess supply or simply does not affect production, then profits are a constant multiple of ecosystem services. More generally, the average value of ecosystem services (earnings divided by ecosystem service flow) overstates value on the margin.

III. An Illustrative Example

The elasticity of profit with respect to ecosystem service flows is equal to one when there are constant returns to scale. There are good reasons to suppose that fixed factors would lead to decreasing returns to scale, however. Most important, when we think about ecosystem services, we often think about the benefits that areas of natural habitat confer on adjacent (or, in some instances, distant) properties. The earnings realized on a particular parcel of land are embodied in its rental and purchase prices. The production process embodied in any particular parcel of land is constrained by at least one obvious fixed factor: the size of the parcel. The increases in production that would be realized by increasing all variable inputs, both market and ecological, in equal proportions on a parcel of a finite size must eventually decline.

What can we say about the value of ecosystem services when there are such decreasing returns to scale? Apparently not very much, in general. We reach this conclusion with an illustrative example. To construct this example we use a functional form that allows both variable returns to scale and some flexibility in the way different inputs interact. The constant elasticity of substitution production function is a convenient form with both properties.

Let the production function have the form

$$q = f(x, \phi, k) = \left(\beta_k k^\rho + \beta_\phi \phi^\rho + \beta_x x^\rho\right)^{\frac{1}{\rho}} \tag{5}$$

where k, β_k, β_ϕ, and β_x are nonnegative parameters and $-\infty < \rho \leq 1$. To ensure that the production function exhibits constant returns to scale we normalize $\beta_k + \beta_\phi + \beta_x = 1$.

The parameter k represents some input available in a fixed quantity. In a plot of land of a given size, for example, k might denote the area of the parcel. Because the production function exhibits constant returns in k, ϕ, and x jointly, it exhibits decreasing returns in ϕ and x if k is fixed. To reduce clutter in subsequent expressions, k will be normalized to one. Although this normalization can be imposed with no additional loss of generality, the choice of units will be significant in interpreting subsequent results. As will be seen shortly, important results turn on whether the flow of ecosystem services is greater or less than the "one" unit assigned to the fixed factor.

Profit can be written as

$$\pi = p\left[\beta_k + \beta_\phi \phi^\rho + \beta_x x^\rho\right]^{\frac{1}{\rho}} - wx \tag{6}$$

Differentiating with respect to x to generate the profit-maximizing condition for the use of the purchased input, we have

$$\beta_x x^{\rho-1} p\left[\beta_k + \beta_\phi \phi^\rho + \beta_x x^\rho\right]^{\frac{1-\rho}{\rho}} = w \tag{7}$$

A similar calculation shows that the value of the marginal product of ecosystem services is

$$\frac{\partial \pi}{\partial \phi} = \beta_\phi \phi^{\rho-1} p\left[\beta_k + \beta_\phi \phi^\rho + \beta_x x^\rho\right]^{\frac{1-\rho}{\rho}} \tag{8}$$

Rearrange Equation 7 to express

$$x^\rho = \frac{\left(\dfrac{w}{\beta_x p}\right)^{\frac{\rho}{\rho-1}}}{1 - \beta_x\left(\dfrac{w}{\beta_x p}\right)^{\frac{\rho}{\rho-1}}}\left[\beta_k + \beta_\phi \phi^\rho\right] \tag{9}$$

and substitute this expression in Equation 9 to find

$$\frac{\partial \pi}{\partial \phi} = \beta_\phi \phi^{\rho-1} p\left[\frac{\beta_k + \beta_\phi \phi^\rho}{1 - \beta_x\left(\dfrac{w}{\beta_x p}\right)^{\frac{\rho}{\rho-1}}}\right]^{\frac{1-\rho}{\rho}} \tag{10}$$

Now from Equation 7 we can write

$$wx = \beta_x x^\rho p\left[\beta_k + \beta_\phi \phi^\rho + \beta_x x^\rho\right]^{\frac{1-\rho}{\rho}} \tag{11}$$

so

$$\pi = p\left[1 - \beta_x\left(\dfrac{w}{\beta_x p}\right)^{\frac{\rho}{\rho-1}}\right]^{\frac{\rho-1}{\rho}}\left[\beta_k + \beta_\phi \phi^\rho\right]^{\frac{1}{\rho}} \tag{12}$$

Then the elasticity of profit with respect to ecosystem services is

$$\frac{\partial \pi/\pi}{\partial \phi/\phi} = \frac{1}{\dfrac{\beta_k}{\beta_\phi}\phi^{-\rho} + 1} \tag{13}$$

A couple of observations are in order. First,

$$\frac{\partial \pi / \pi}{\partial \phi / \phi} \leq 1$$

with the elasticity equal to one only if

- $\beta_k = 0$: the fixed factor is not important in production, meaning that the production process exhibits constant returns to scale.

- *in the limit as $\phi \rightarrow \infty$ if $\rho > 0$.* Recall that if $\rho \rightarrow -\infty$, the production function is of the Leontief (fixed proportions) form. If $\rho = 1$, ecosystem services are perfect substitutes for the other inputs. Cases in which $\rho > 0$ are, then, instances in which ecosystem services are "relatively good substitutes" for other inputs. As the flow of ecosystem services becomes large, then, the other inputs are of little importance and production is essentially proportional to ecosystem service flow.

- *in the limit as $\phi \rightarrow 0$ if $\rho < 0$.* This is the opposite of the case just considered. For $\rho < 0$, inputs are "relatively complementary," so as the flow of ecosystem services declines, it constitutes a constraining factor on production possibilities. Again, the other inputs are of little importance, not this time because they substitute for ecosystem service flows, but because they are useless without them.

- *in the limit as $\rho \rightarrow -\infty$ if $\phi < 1$.* Recall that we normalized the units in which the fixed input k is measured so as to make $k = 1$. If $\phi < 1$ and $\rho \rightarrow -\infty$, ecosystem services are the limiting factor of production, and output will increase linearly with an increase in their provision until ϕ reaches one.

Similarly, approaches zero if:

- if β_ϕ *approaches zero.* Ecosystem services are not important in production.

- *in the limit as $\phi \rightarrow \infty$ if $\rho < 0$.* This is the most intuitive condition; ϕ is simply not scarce.

- *in the limit as $\phi \rightarrow 0$ if $\rho > 0$.* Here other inputs are relatively good substitutes for ecosystem services and changing the supply of ecosystem services when they are only provided in a trickle to begin with makes relatively little difference.

- *in the limit as $\rho \rightarrow -\infty$ if $\phi > 1$.* This is the opposite of the last item in our first set of conditions . When $\phi > 1$, under the convention that the fixed factor k is normalized to one, and as $\rho \rightarrow -\infty$, the fixed factor is the limiting factor of production and additional quantities of ecosystem services are superfluous.

IV. Discussion and Conclusion

Although the conceptual basis for estimating the value of ecosystem services is straightforward, limits on data availability constrain our ability to conduct such exercises. The average contribution of ecosystem services to earnings (as represented in practice by land value) constitutes an upper bound

on value, but this bound may not comprise a plausible estimate because other fixed factors may claim rents.

We do not want to push the implications of a simple and stylized model too far, but the results of the exercise we have conducted may be suggestive. We might expect observed property values to be most sensitive to changes in ecosystem service flows (a) when ecosystem services do not have good substitutes and (b) when they comprise the limiting constraint on production possibilities. This suggestion also implies that, for a given average value of ecosystem services, marginal value is greatest when there is a possible discontinuity. As long as ecosystem services are a limiting constraint, they can be very valuable, but this assumption would also imply that they can, beyond a certain level, be in excess supply and hence not valuable on the margin. In this sense, our results recall Diamond's (1996) critique of work by Hanemann (1991) and by others on the interpretation of contingent valuation surveys. In both our context and that studied by other authors, theory places few restrictions on values, but it does suggest some tests of consistency.[6]

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[6] Such consistency tests are probably weaker in our context. Diamond (1996) demonstrates that certain apparent anomalies of stated preferences can be reconciled if the income elasticity of willingness to pay is large enough. In our context, the analogous condition would involve the elasticity of ecosystem service value with respect to the quantity of the other fixed factor of production. The essence of the ecosystem service valuation problem, however, is that it is impossible to distinguish between rents accruing to ecosystem services and those that can be ascribed to other fixed factors.

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