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ANALYSIS

# Valuing ecosystem services: A shadow price for net primary production

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ARTICLE INFO

*Article history:*
Received 28 August 2006
Received in revised form
8 March 2007
Accepted 8 March 2007
Available online 3 May 2007

*Keywords:*
Ecosystem valuation
Net primary Production
Ecosystem services

ABSTRACT

We analyze the contribution of ecosystem services to GDP and use this contribution to calculate an empirical price for ecosystem services. Net primary production is used as a proxy for ecosystem services and, along with capital and labor, is used to estimate a Cobb Douglas production function from an international panel. A positive output elasticity for net primary production probably measures both marketed and nonmarketed contributions of ecosystems services. The production function is used to calculate the marginal product of net primary production, which is the shadow price for ecosystem services. The shadow price generally is greatest for developed nations, which have larger technical scalars and use less net primary production per unit output. The rate of technical substitution indicates that the quantity of capital needed to replace a unit of net primary production tends to increase with economic development, and this rate of replacement may ultimately constrain economic growth.

Published by Elsevier B.V.

## 1. Introduction

The "Holy Grail" for environmental economists would include empirical prices for ecosystem services. Prices are warranted because ecosystems contribute to economic well being in ways that extend well beyond aesthetic amenities (Millennium Ecosystem Assessment, 2005; Imhoff et al., 2004; Brock and Xepapadeas, 2003; Daily et al., 2000; Costanza et al., 1997; Vitousek, 1994). Contributions include the production of natural resources, the dilution and detoxification of wastes, the provision of a hospitable climate, and biodiversity.

Many of these services are not provided through the market because the services and/or portions of the environment that provide them are non-appropriable. That is, they cannot be owned therefore access cannot be controlled. These conditions create an externality that prevents the market from allocating ecosystem services efficiently and the resultant inefficiency often reduces their provision. As an externality, degradation will continue without intervention.

The market cannot recognize the economic impact of environmental degradation if ecosystem services do not have a price. For example, existing technologies that reduce the environmental impact of human activity on ecosystem services are not fully implemented because the environmental services they preserve are free (Millennium Ecosystem Assessment, 2005). If empirical prices for ecosystem services were available, degradation could be reduced using economically efficient market based mechanisms.

Here, we evaluate two fundamental questions about ecosystem services: (1) do ecosystem services contribute to

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0921-8009/$ - see front matter. Published by Elsevier B.V.
doi:10.1016/j.ecolecon.2007.03.009

economic activity, as measured by traditional metrics, such as Gross Domestic Product, and (2) can this contribution be used to calculate a shadow price for ecosystem services? To answer these questions, net primary production is used as an ecologically meaningful measure for the ecosystem services that are rendered by natural capital. Using annual values for net primary production, along with capital and labor, we estimate a Cobb Douglas production function from an international panel. The positive output elasticity for net primary production probably measures both the market and nonmarket contributions of ecosystem services. We use the estimated output elasticities and technical scalars to calculate the marginal product of net primary production, which represents the shadow price for ecosystem services. The shadow price generally is greatest for developed nations, which have larger technical scalars and use less net primary production per unit output. We also calculate the rate of technical substitution. Our results indicate that the quantity of capital needed to replace a unit of net primary production tends to increase with economic development. This rate of replacement may ultimately constrain economic growth.

## 2. Ecosystem services and economic activity

### 2.1. *How do ecosystem services contribute to traditional measures of economic activity?*

The Millennium Ecosystem Assessment (2005) identifies three types of ecosystem services; provisioning services, regulating services, and cultural services. Provisioning services include food, fiber, freshwater, genetic resources, and chemicals. The economic value for many of these services, such as value added in agriculture, is included in the system of national accounts that is used to calculate Gross Domestic Product and other measures of economic activity. Despite inclusion, their importance may be understated. In several African, European, and Asian nations, the economic benefits of converting forests to pasture or using them as a source of timber and fuel wood are smaller than the loss of non-marketed services such as carbon sequestration, watershed protection, and recreation and hunting (Millennium Ecosystem Assessment, 2005).

These non-marketed services, along with the regulation of climate, erosion, pests, and natural hazards, are known as regulating services. Many of these services are not priced by the market, nonetheless, they contribute to economic output two ways. Some regulating services increase economic output directly. For example, mangrove ecosystems regulate water quality and control erosion, which allows the local ecosystem to support a larger population of fish. Higher densities increase the quantity of fish caught, which increase the value of output (Barbier, 2000; Barbier and Ian Strand, 1998). Efforts to calculate the direct market valuation of regulating services has been limited by a lack of data and a clear understanding of how the ecosystem, the service being valued, and the marketed commodity are linked (Chee, 2004; Daily et al., 2000).

Regulating services also increase output indirectly in ways that can be understood via the economic notion of opportunity costs. For example, natural wetlands purify drinking water and provide flood control. Although these services usually are not priced by the market, they increase economic output by increasing the availability of capital and labor that can be used elsewhere in the economy (Kaufmann, 1995). To illustrate, suppose that natural wetlands and the services they provide are destroyed. To maintain economic well-being, wetland ecosystem services would be replaced by a water filtration plant and a system of dams and levees. Their construction and operation would consume capital and labor that otherwise would be available to produce other goods and services. The value of these other goods and services, which are lost due to the construction and operation of the filtration plant, dams, and levees, are termed opportunity costs, and represent the economic value of the ecosystem services provided free by the wetlands.

These opportunity costs sometimes can be quantified using the concept of avoided costs, which are based on the replacement costs of human infrastructure. For example, wetlands are valued based on the avoided costs of human infrastructure for flood control. A similar technique, replacement/restoration cost, values environmental services based on the price of market services that provide the same utility.

The third type of ecosystem services is cultural services. These include spiritual and religious values, aesthetic values, and recreation and ecotourism. Many ecosystem services used for recreation and ecotourism are included in the system of national accounts. Their contribution often is measured using travel cost methods, which quantify the money and time that people spend on travel to an ecosystem service. Aesthetic values represent the quality of natural lands. A portion of their economic value is included by the higher rents that consumers are willing to pay for land with nice views, etc. This contribution has been measured using hedonic prices, which attempt to isolate the value contributed by a specific trait or aesthetic quality (King and Sinden, 1988). Finally spiritual and religious values can raise the value of particular landscapes, including those that will never be visited but which have an existence value. For example, many consumers in developed nations value tropical rainforests or polar bears even though they may never see either *in situ*.

### 2.2. *An empirical measure of ecosystem services*

Many provisioning and regulating services can be proxied by terrestrial net primary production. Terrestrial net primary production is the difference between the energy fixed by producers (largely plants), which is termed gross primary production, and the energy they use for maintenance. Net primary production represents the amount of energy used by plants for storage, growth, and reproduction. These energy flows support consumers and detritivores. As such, net primary production can be viewed as a flow that maintains the stock of natural capital that generates ecosystem services. This assumption is consistent with previous analyses—for example the value of services provided by the biomes listed in Table 2 of Costanza et al. (1997) is positively correlated with their relative rates of net primary production.

Net primary production is positively correlated with the flow of many provisioning and regulating services. In general, landscapes with high net primary production generate more food, timber, or fiber than less productive landscapes. The global distribution of biodiversity and the services it provides, such as

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