Using Ecological Production Theory to Define and Select Environmental Commodities for Nonmarket Valuation

James Boyd and Alan Krupnick

Economic analyses of nature must somehow define the "environmental commodities" to which values are attached. We articulate principles to guide the choice and interpretation of nonmarket commodities. We describe how complex natural systems can be decomposed consistent with "ecological production theory," which, like conventional production theory, distinguishes between biophysical inputs, process, and outputs. We argue that a systems approach to the decomposition and presentation of natural commodities can inform and possibly improve the validity of nonmarket environmental valuation studies. We raise concerns about interpretation, usefulness, and accuracy of benefit estimates derived without reference to ecological production theory.

Key Words: commodities, endpoints, nonmarket valuation, revealed preference, stated preference

We develop a systems-based approach to ecological valuation that draws on production theory. In part, production theory is useful because it allows economists to depict production as a system of inter-related commodities and processes. We apply production theory to the analysis of ecosystem goods and services by describing ecosystems as collections of commodities linked by a range of biophysical processes and then discuss the implications of a systems approach to ecology for nonmarket valuation. Our conclusion is that a systems-oriented, ecological-production-based approach to commodity definition has important implications for the quality and interpretation of stated and revealed willingness to pay (WTP) estimates.[1] Ecological production theory also leads to suggestions for new stated preference survey protocols. And benefit transfers

[1] This discussion is primarily applicable to stated preference techniques in which the commodity to be valued can be defined by the researcher. A large literature discusses revealed preference revelation, including a paper in this volume that draws on the experimental economics literature to design such mechanisms (Swallow 2013).

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will clearly gain from the clearer, more consistent commodity definitions we feel are possible via systematic depictions of ecological production.

Ecological systems are complex. Economists using stated preference techniques to value ecological changes face a daunting task: how to decompose these systems into commodities that are both consistent with ecological science and meaningful to respondents. We argue that ecological production theory bears directly on the commodity definition issue. It helps identify the linkages necessary to integrate ecological science with commodities useful to valuation. It also helps address a set of cognitive issues that arise when stated preference subjects are asked to assign value to environmental commodities that are complex or ambiguous. Production theory also helps avoid double-counting and clarifies the interpretation of both elicited and revealed WTP values.

Overall, we hope to contribute to a larger conversation within nonmarket valuation about commodity definition. The difficulties associated with deriving WTP estimates have, in our view, distracted attention from a more basic issue: what commodities are actually creating value and what are the relationships between those commodities? Some of the arguments presented here raise questions about the validity and/or interpretability of stated and revealed preferences. Our goal, though, is to generate new questions and insight into how nonmarket valuations should be conducted empirically.

A virtue of market commodities (if you are an analyst) is that markets not only yield prices but define units of consumption. A grocery store is full of cans, boxes, loaves, and bunches. The number of these units bought yields a set of quantity measures to which prices can be attached. A key challenge faced by economists is clarification of the nonmarket commodities that yield utility. Nature presents us with many possible units from which to choose. Should we use the units governments monitor? Should we use units used in economic studies? The ones used by ecologists? Should we use what laypeople tell us matters most to them?

Nonmarket commodity definition is a complicated issue. A review of the nonmarket literature reveals a lack of uniformity in the way commodities are chosen and presented. Also, we argue that certain kinds of commodities used in the literature are more likely than others to lead to inaccurate valuations, scenario rejection in stated preference surveys, and misinterpretation of WTP estimates by policy audiences. Our hope for this discussion is to stimulate debate on ways to make commodity definitions clearer and more rigorous. Indeed, one very recent paper that is published in this volume (Johnston et al. 2013) is evidence of growing interest in the theoretical and empirical issues taken up here.

Another reason to discuss commodity definition is the growing interdisciplinary ecosystem service movement. Ecosystem service analysis explicitly demands a linkage between ecological outcomes and economic consequences. This elevates the importance of getting units right or at least clarifying why economic analysts use the commodity units we do. The ultimate goal is for natural scientists and economists to describe ecological changes in the same relevant and meaningful units.

The next section describes ecological production theory, relates it to conventional production theory, and discusses valuation issues associated with the distinction between ecological inputs, processes, and outputs. The third section applies ecological production theory to the definition of commodities in stated preference studies. We conducted a survey of commodities used in the literature and interpret a selection of those through the lens of ecological production theory. In so doing, we identify a number of areas in which production theory potentially can improve the accuracy of surveys, acceptance of scenarios by respondents, and subsequent interpretation of elicited WTP values by policymakers. We argue that ecological production theory can help address ambiguities and confusion associated with the depiction of environmental resources. Because environmental resources are inherently inter-related, failing to depict those relationships systematically is a potentially important source of valuation problems. In the final section, we conclude by discussing the broader implications of ecological production theory for design of stated preference experiments and for design and interpretation of revealed preference studies.

An Ecological Systems Approach to Commodity Definition

The principles that guide the decomposition and aggregation of nonmarket goods are the subject of this section.[2] Our approach is to describe nonmarket environmental commodities in the context of *systems of ecological production*. We then compare the commodity definition approach suggested by a systems approach to commodities used in the stated preference literature. We find important differences between the two. These differences suggest that a dialogue between proponents of a systems approach and empirical practice may be illuminating and could advance the development of stated preference valuation techniques. We also argue that a systems approach to commodity definition will improve the interpretability of elicited valuations by decision-makers in, for example, a cost-benefit or environmental accounting setting.

Systems

Nature can be thought of as a complex system in which physical and biotic conditions are mediated and transformed by biological, physical, chemical, hydrological, and atmospheric processes. We employ three basic terms to describe an *ecological system*: biophysical inputs, outputs, and production functions.

Any natural process, by definition, transforms a set of inputs into a different set of outputs—much like an industrial process transforms inputs like labor and capital into outputs like cars and loaves of bread. Hydrological processes transform rainfall into ground and surface water. Biological and chemical processes transform water of one quality into water of a different quality. Reproductive, forage, and migratory processes relate biotic and physical conditions to the abundance of species. Food chains convert one form of biomass into another. Wetland processes transform the scale, location, and speed of flood pulses. Sequestration processes affect the release, and in some cases transformation, of chemical inputs to water or the atmosphere. Even a process as simple as "shading" relates tree canopies to regulation of water temperature. When ecologists or other natural scientists speak of ecological processes or functions, they are referring to the transformation of one set of biophysical conditions into another (Figure 1). Ecologists and economists

[2] See Johnston et al. (2013) for a mathematical treatment of some of these principles using the utility function rather than a production function.

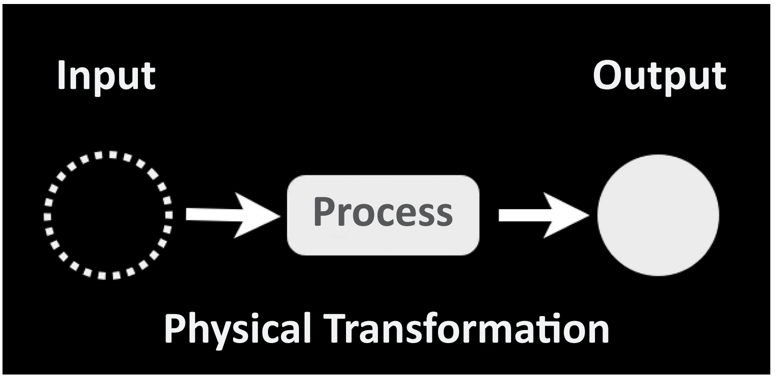

Figure 1

refer to these processes as biophysical production functions (Environmental Protection Agency 2009, Daily and Matson 2008, Boyd 2007).

Biophysical inputs are environmental features or conditions that are converted via natural processes into different environmental features or conditions. The different environmental features or conditions are the *outputs* of the biophysical process in question. We refer to biophysical processes that transform inputs into outputs as *biophysical production functions*. Production functions are the causal link between one set of features or qualities and other features or qualities.

Ecological Endpoints Defined

To relate an ecological systems approach to economic valuation, we introduce one additional term important to our argument: ecological endpoint. *Ecological endpoints* are a subset of biophysical outputs. In economic parlance, they are biophysical outputs that *directly* enter firm or home production.[3] Related work on this subject refers to these outcomes as "final ecosystem goods and services" (Ringold et al. 2013). Economists refer to what consumers know and the choices they make as inputs to a "household production" or "utility" function. Inputs to a household production function include the household's possessions and labor. But there are many nonmarket inputs to household production and utility, including leisure time and ecological commodities. Examples of the latter include open space in the neighborhood, birds at the birdfeeder, and clean water from the well. Likewise, a firm's production process relies on direct inputs that are biophysical, such as water to cool generators or timber used to make lumber.

The distinction between biophysical outputs that are ecological endpoints and biophysical outputs that are not ecological endpoints is that endpoints *directly* enter home production. Outputs (or inputs, or even biophysical processes for that matter) that are not endpoints *indirectly* enter home production. Direct inputs to a household or firm production function (ecological

[3] We are not saying that inputs or even production processes cannot enter respondents' utility functions. However, by definition, inputs and processes are further back in the chain of biophysical production. This means they require further biophysical translation into outcomes that are interpretable by nonexperts (who will, in general, lack detailed knowledge of production relationships). That process of translation introduces a set of cognitive and interpretive issues that we discuss hereafter.

endpoints) are things we experience, things we make choices about, and things that have tangible meaning. Many things we can measure in nature and that are important features of the ecological system do not have these properties. The dissolved oxygen level in water, for example, is not directly experienced, is not typically the subject of household choice, and is not tangibly meaningful to most nonexperts. But there are direct inputs to home production that depend on dissolved oxygen as an input. Dissolved oxygen can affect fish populations and water clarity and odor, for example. These commodities are much more likely to be experienced directly, to bear directly on household choices, or to be identified as intuitively important to utility. If so, we can describe them as ecological endpoints to a system involving dissolved oxygen (an input to the endpoints' production).

Another way of defining ecological endpoints is that they are commodities that require little or no subsequent biophysical translation to make their relevance to utility clear. In other words, dissolved oxygen is not an endpoint because its role in utility requires understanding its role in production of subsequent biophysical commodities.

> **Definition:** *Ecological endpoints* are meaningful biophysical outputs that do not require expert knowledge of biophysical production functions to determine their economic value. They are direct inputs to household production.
>
> In contrast, commodities that are not endpoints may enter firm and home production but do so only after being transformed via a subsequent biophysical production function.

To convey the distinction between ecological endpoints and biophysical commodities that are not endpoints, consider the examples in Table 1. Consider a firm or household asked to place a value on the commodities on the lefthand side of the table. Are lower surface water pH levels valuable to households? Yes, but not directly. Why is lower pH valuable? One reason is that it allows for habitats more suitable to fish and bird species. If a household directly values more fish and birds, it indirectly values lower pH levels. Note, though, that the value of lower pH must be inferred from two pieces of information: (i) the value of the direct fish and bird inputs to household production and (ii) the production relationship between surface water pH and fish and bird abundance. Because the value of pH can only be inferred via knowledge of the production relationship, we do *not* call it an endpoint. In contrast, the abundance of fish

Table 1. The Distinction between Outputs and Endpoints

Biophysical Input or Output	Biophysical Process	Ecological Endpoint
Surface water pH	Habitat and toxicity effects	Fish, bird abundance
Acres of habitat	Forage, reproduction, migration	Species abundance
Wetland acres	Hydrological processes	Reductions in flood severity
Urban forest acres	Shading and sequestration	Air quality and temperature
Vegetated riparian border	Erosion processes	Sediment loadings to reservoirs

and birds requires no further biophysical transformation to make its role in household production clear.[4] Thus, fish abundance is an endpoint.

Consider another example from the table. A household or firm owning real estate in a floodplain may understand that wetlands are valuable because they reduce the severity of flood pulses and property damage. But the value of the wetland must again be inferred from the hydrological processes that relate wetlands to the probability, height, speed, and location of flooding (the hydrograph). In this case, the hydrograph is the directly consumed nonmarket good (and thus, by our definition, an ecological endpoint). Wetlands' role in this example is as a valuable, but indirectly valuable, commodity.[5]

Similarly, eagle or caribou habitat is valuable but only indirectly. The habitat's value is derived from knowledge of the biophysical production relationship between input (habitat) and the output of a habitat (a healthier and more abundant eagle or caribou population).[6]

Are species mortality statistics an endpoint? Consider a study that presents respondents with the number of individual animals saved or kept healthy by a management action. Is the number saved an ideal endpoint? In some cases, yes, but only when the life of individual animals is considered important. In cases involving domestic animals, charismatic species (harp seals, for example), or endangered species, individual deaths may matter to people. In other cases, however, individual species mortalities may not be the final commodity and thus not ideal for valuation purposes. Consider fish killed by cooling water intakes. To anglers, individual fish mortalities matter but indirectly. Individual mortalities matter because they indirectly influence stock abundance, but it is the steady state stock that directly matters. The relationship between individual mortalities and steady state stocks is complicated and best left to biologists to ascertain. Accordingly, stock changes are a preferable endpoint.

As a final example, consider almost any biophysical condition that is defined in technical or scientific terms. It is common in ecology to measure things like dissolved oxygen, turbidity, benthic disturbance, and trophic change. Technical outcome measures like these almost always signify the need to subsequently translate the measure into outcomes that are more meaningful to nontechnical audiences (i.e., firms and households) to convey their economic importance. Is less benthic disturbance valuable? Yes, but because it is an indicator of the health of fish and amphibian species in the river. A benthic disturbance measure by itself may be almost meaningless to firms and households and thus, in this case, is not an endpoint. Rather, the health of species signified by the benthic measure is what is directly and economically meaningful to households.

The distinction between inputs and endpoints can be illustrated by the common practice of "mapping" technical criteria into more meaningful outcomes for respondents. Carson and Mitchell's (1993) water-quality ladder translates numerical water-quality measures that lack meaning to nonexperts into nontechnical categories like "swimmable," "fishable," and "boatable." Bateman et al. (2005, p. 280) created an analogous ladder to relate lake acidity

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[4] The household may need to know about the economic production of fish and birds into welfare, however, such as the ability to access the fish and birds via foot or car or the role of complementary economic goods like fishing and birdwatching gear.

[5] As we will discuss later, in a more elaborated system view of wetlands, they will play a role as both endpoints and inputs to biophysical processes.

[6] Here we are using a strict definition of the term "habitat." If "habitat" instead is taken more loosely to mean "natural land cover or open space," its aesthetic qualities are directly valuable.

levels into more meaningful commodities (effects on species) to "convey the biological impacts and risks associated with increasing levels of acidity in a manner that can be linked to, but does not require presentation of pH levels." In our language, pH levels are not meaningful to nonexperts.

The "water-quality ladder" developed at Resources for the Future and deployed in nationwide contingent valuation surveys by Mitchell and Carson (1993) is an interesting example of commodity definition. Because people have difficulty interpreting the influence of numeric water-quality measures (like dissolved oxygen levels) on their well-being, the water-quality ladder was developed to translate numeric criteria into more understandable commodities.[7] Largely because the terms swimmable, fishable, and boatable were used in the Clean Water Act to differentiate water quality levels, Mitchell and Carson used those terms as distinct commodities to be valued by respondents. The commodities had a greater resemblance to endpoints than dissolved oxygen levels since they had greater meaning to households. They are a bit vague, however.

In their survey instrument, Mitchell and Carson (1989) had to explain the meaning of the commodities more specifically. For example, the worst quality water was described as having "oil, raw sewage, and trash in it" and as being "dangerous to human health." Boatable water would "not harm you if you happened to fall into it for a short time." Fishable water was described in this way: "although some kinds of fish can live in boatable water, it is only when water gets [fishably] clean that game fish like bass can live in it." (Mitchell and Carson 1989, p. 2447). These descriptors come closer to what we call endpoints. They are concrete, not vague, and are likely to be what people actually find meaningful about water quality. Note that the descriptors relate to specific recreational species populations (bass), human health risks, and observable disamenities like sewage and trash.

Ideally, valuations would be attached to specific components such as these and with even more attention to detail. For example, what does dangerous to human health mean? Getting a rash, diarrhea, dying prematurely? Without definition of these more specific public health commodities, respondents are left to their own interpretation of "dangerous."

At this juncture, it is useful to compare and contrast "ecological endpoints" to other terms encountered in the literature. In particular, are ecological endpoints the same thing as "ecosystem services?" Semantic confusion clouds discussion of ecosystem services because the term means different things in different disciplines (Boyd and Banzhaf 2007). Generally speaking, ecologists think of ecosystem services as the biophysical processes that give rise to economic benefits. In ecology, processes like nutrient cycling, atmospheric regulation, pollination, and seed dispersal are called services. In contrast, economists often think of ecosystem services as the economic benefits of ecosystems. They refer to recreation, flood damage avoided, and aesthetic benefits as ecosystem services. Because the term is used in such different ways, we choose to avoid it altogether.

We emphasize that what people perceive as direct inputs to their home production is a broad, complex empirical and psychological question, an issue we return to in the next section. Our assertion at this point is simply

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[7] See Johnston et al. (1995, p. 64), which analyzed use of the water-quality ladder in focus group settings: "focus group participants viewed and thought about water quality in terms of the symptoms of pollution that they had experienced, symptoms that included levels of algal growth, foul smells, visible scum, and trash."

that ecological commodities can be distinguished by the degree to which they require understanding of biophysical production relationships to "translate" them into outcomes understood by people in firm and home production and the degree to which they are meaningful to individuals in making choices affecting their utility.[8]

We also emphasize that direct relevance to household well-being does not imply that the commodity must be physically present, tangible, or consumed in some way. Consider the important case of the existence of and non-use values associated with something like endangered species. Many people clearly value the existence of certain species even if they will never see, hear, or touch them. The existence of such a species is a final commodity because what people care about in this case is exactly that: the species' existence. No further biophysical translation is necessary. Thus, we can say that the existence commodity directly enters household production even though there is no tangible physical experience of the commodity.

Finally, note that the distinction between intermediate outputs and endpoints mirrors the distinction between intermediate and final goods in economic accounts. To avoid double-counting of value added or social benefits, economic accounts distinguish between intermediate and final goods. For the purpose of accounting for gross domestic product, for example, only final goods are tracked and weighted since the value of inputs is captured in the value of the final product.[9]

Ecological Commodities from the Natural Science Perspective

As a general rule, the units measured and reported in the natural sciences are most often what we term intermediate inputs rather than endpoints. This is one reason it remains difficult to integrate the biophysical science of ecosystem services with the economic evaluation of outcomes. As an example, ecosystem managers and regulators often emphasize indicators like an "aquatic macroinvertebrate community index" (Plafkin et al. 1989). This index is a useful measure because it acts as a proxy for food availability for fish and birds, indicates the level of chronic stress on all aquatic organisms, and may be correlated with abundance of fish species or fish diversity. But clearly this type of indicator does not satisfy the conditions of an endpoint. It is technical and unobservable to households, and its relationship to value requires knowledge of subsequent biophysical processes and outcomes.

A full inventory of the qualities, features, and conditions derived from and measured by ecological science is beyond the scope of our discussion. However, it is instructive to compare endpoints as we define them to endpoints as defined by the Environmental Protection Agency (EPA). In the 1990s, EPA created an Environmental Monitoring and Assessment Program (EMAP) designed to conduct a long-term assessment of the current status and trends

[8] Our definition of endpoints also relates to the use of "objective" versus "perceived" environmental quality measures as independent variables in revealed preference studies. Studies that have addressed this issue found that perceptions generally outperform objective measures (Adamowicz et al. 1997) but not always (Poor et al. 2001).

[9] Counting inputs and outputs in a single economic index double-counts the inputs' role in adding value to the final good. See Dernburg and McDougall (1972, p. 63): "What is wanted . . . is an unduplicated total that measures the flow of product to the final consumer. The Department of Commerce defines a final good as one produced and/or purchased but not resold . . . intermediate goods are excluded from the [gross national product] total to avoid duplication."

in ecological conditions at a regional scale (Hunsaker and Carpenter 1990, Hunsaker 1993, Lear and Chapman 1994). More recently, the agency developed Generic Ecological Assessment Endpoints (EPA 2003). In both cases, most of the endpoints identified are different from the kind we propose (in large part because they were designed to address legislative, policy, and regulatory mandates, not economic valuation).[10]

Schiller et al. (2001) conducted an analysis that presented EMAP indicators to lay audiences in a focus group format and found that the agency needed "to develop language that simultaneously fit within both scientists' and nonscientists' different frames of reference, such that resulting indicators were at once technically accurate and understandable" (online). As we argue here, biophysical measures that work across "different frames of reference" are fundamental to coordinated biophysical and social evaluation.

The Dual Nature of Ecological Commodities

An important feature of ecological systems is that the outputs of one biophysical process often become inputs to subsequent biophysical processes. This means that a given biophysical commodity can simultaneously be both an input and an endpoint.

> **Definition:** *Dual commodities* are both endpoints with direct relevance and meaning to home production and inputs to subsequent biophysical production of different ecological endpoints. This dual nature means that a given commodity cannot be valued as a single thing without relating it to the set of other endpoints to which it contributes.

Consider a fish, bird, or mammal population that is valuable recreationally or commercially. The abundance of that population is an endpoint due to its direct relevance to recreation. On the other hand, any species except those at the highest trophic levels are part of the food web necessary for other species. A trout population is both an endpoint (for an angler) and an input for households that value the existence of bird species dependent on trout for food.

Consider the other examples in Table 2. Acres of forest are a plausible endpoint yielding household aesthetic benefits if the forest can be viewed from a residential neighborhood or by a recreational user, by a commuter on the way to work, or in the mind of a person who simply values the forest's existence. On the other hand, forest acres also are an input to a range of subsequent biophysical production processes, including species that depend on the forest as habitat, water filtration and storage, an influence on air quality, and reduction of sediment.

Wetland acres are similar. They may be directly valuable (and thus an endpoint by our definition) to households that value natural open space. They may be indirectly valuable (and thus inputs by our definition) for the role they play in water purification and storage, habitat for valued species, and flood pulse attenuation.

Is "biodiversity" an endpoint? Biodiversity is a "commodity" likely to confuse stated preference respondents because it is dual in nature. Biodiversity is an end in itself—and thus an endpoint—when related to existence values. Preventing

[10] These endpoints were developed to satisfy the legal and technical needs of the agency rather than to foster economic assessment (EPA 2003, p. 5).

Table 2. Dual Commodities

Endpoint	Biophysical Process	Different Endpoint
Trout abundance	Forage and predation relationships	Bird abundance
Forest acres	Hydrological processes	Species abundance
Wetland acres	Hydrological processes	Flood pulse regulation

extinctions is directly valuable to many people. Biodiversity measures that count the existence of species or extinctions are direct biophysical measures of what people care about—the number of species we are saving. Local biodiversity, which measures the presence of particular species on a particular landscape, is also an endpoint since households may consider local biodiversity aesthetically or recreationally valuable. The diversity of bird species in a particular location is of direct value to birders, for example.

However, biodiversity measures also may be interpreted as proxies for the overall health of the ecological system. In that sense, biodiversity is not an endpoint; rather, it is an intermediate commodity or a "leading indicator" of system conditions. As such, it is not a commodity amenable to household valuation. What is the relationship of biodiversity to the ultimate production of final biophysical commodities households are familiar with and value? This is the subject of active research in the scientific community, of course. And respondents will generically understand that biodiversity signals the health of various inputs necessary to continued provision of other endpoints. But when we view biodiversity as a signal of systemic condition, we cannot expect the public to make the translation of biodiversity measures into subsequent biophysical production of other endpoints they can more easily evaluate. The dual nature of biodiversity measures (as endpoint and intermediate signal of systemic health) can be expected to confound valuations unless that dual nature is explicitly clarified.

An obvious corollary to this discussion is that an ecological commodity often is a bundle of multiple endpoints and inputs to subsequent biophysical production. Bundling and the disaggregation of environmental commodities for valuation is an important concept in what follows. Generic (or "lumpy") commodities like rivers, forests, open space, and even wetlands are, from the systems perspective, bundles of linked inputs and outputs that in principle can be disaggregated into finer components related by distinct biophysical production functions and their ultimate role in human well-being.

Parsimonious Depiction of a System

It is useful in the following discussion to refer to a simple description of an ecological system that features inputs, outputs, production functions, and endpoints. Figure 2 describes the conversion by one biophysical process of two biophysical inputs into a dual commodity (it is both an endpoint and an input to a second, subsequent biophysical process that yields a second endpoint).

To illustrate the way in which this simple, generic system maps into real examples, consider the following ecologically plausible production relationships

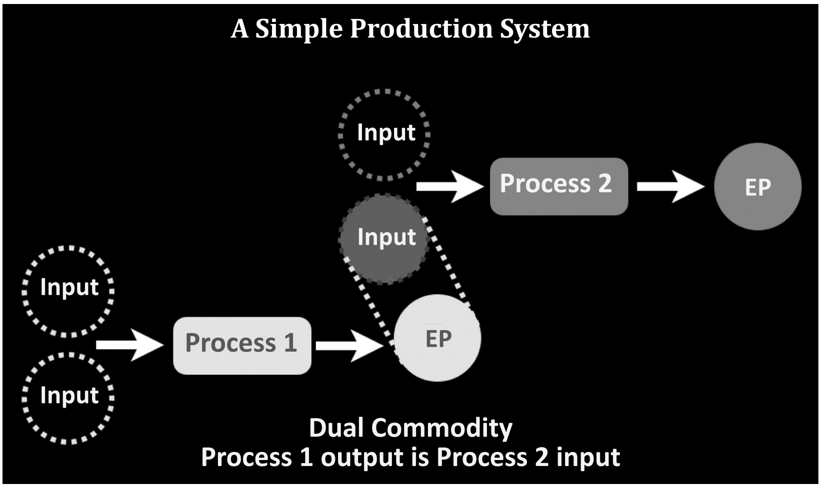

Figure 2

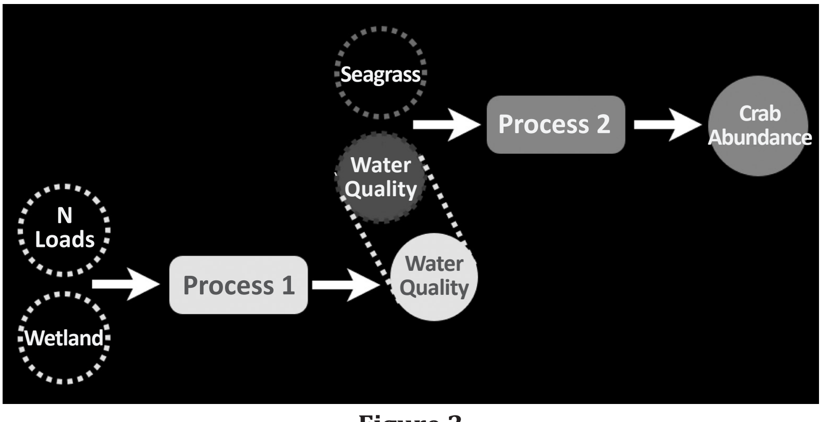

Figure 3

linked by commodities that are dual in nature. In Figure 3, wetlands are an input to production of better water quality. Wetlands and the hydrological, soil, and chemical processes they embody sequester and convert fertilizer and other nutrients, thereby yielding improved water quality. This improved water quality is an endpoint since it can be of direct relevance to home production (households' welfare based on aesthetics and recreation is directly improved by clean water). In addition, however, that same clean water is an input to habitat processes (forage, growth, reproduction) of species like blue crabs. These processes yield another endpoint: blue crab abundance.

Or consider a second example in which forest cover is an input to hydrologic processes that yield a subsequent surface water hydrograph (the speed, depth, and duration of flood pulses) (see Figure 4). The sum of the characteristics of the hydrograph is an endpoint since it can be of direct relevance to firm and home production (welfare arising from avoided flood damage is directly influenced

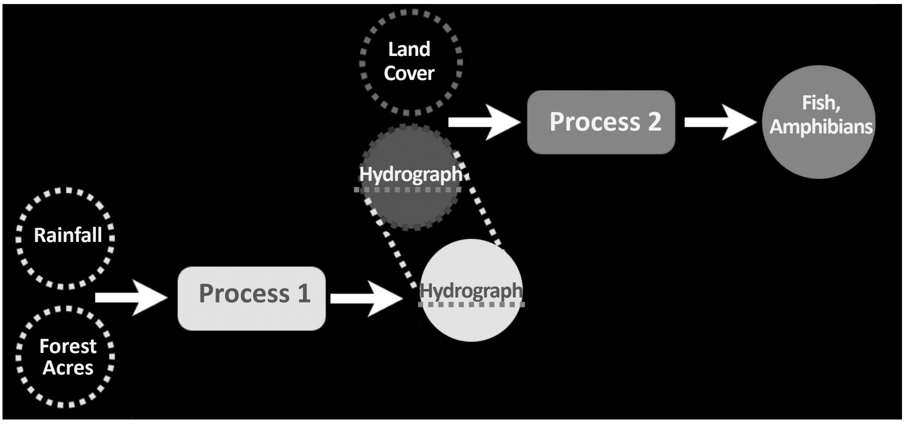

Figure 4

by the hydrograph). In addition, the hydrograph is an input to habitat processes for fish and amphibians with their populations being endpoints.[11]

In our discussion of valuation techniques, concepts like bundled ecological commodities and their disaggregation, respondents' knowledge of systems of production, and the dual nature of many commodities will be important. Real ecosystems are more complex than these examples suggest, of course. But even oversimplified systems such as these examples help illustrate important valuation issues.

Derivation of Values in Production and Accounting Theory

Before turning to the challenge of nonmarket valuation, it is useful to interpret the valuation of inputs and outputs through the lens of conventional production and accounting theory. Consider again the parsimonious system depicted in Figure 2. If processes 1 and 2 are thought of as "factories," the figure depicts an economy in which factory 1 produces a good that is both final (sold directly to consumers) and intermediate (sold to a different factory that uses it to make a different final good).

How do we calculate the value of this economy and its component inputs and outputs? In a conventional market context where prices and demand responses are observable, the value of the system is equal to the social surplus generated by the two final goods. It is not appropriate to add the surplus generated by factory 1's production of the input used by factory 2 to derive the system's value since that benefit is captured in the surplus generated by factory 2's final output. To include the surplus generated by production of the second factory's input would be to double-count the surplus.

This rationale motivates the distinction between final and intermediate goods in economic accounting theory as well. Recall that gross domestic product as an aggregate measure of consumption weights only final consumer goods

[11] Flooding, like forest fires, can be an important contributor to the health and renewal of habitats. In fact, the regulation of flood behavior by dams is considered in some cases to be a threat to native riverine species.

and services to avoid the double-counting that would arise from inclusion of intermediate goods and service in the index.[12]

In a conventional market setting, the analyst may possess detailed information on prices and quantities demanded in both the input and the output market. If so, surplus associated with both inputs and outputs can be measured relatively directly. In other cases, production theory allows the welfare derived from inputs (which may be unobservable or unpriced) to be inferred from knowledge of the production function and output surplus. Alternatively, if knowledge of the output market is limited, output-based welfare effects can be inferred from the production function and surplus generated by the input (Just, Hueth, and Schmitz 2004). Inferring output (input) welfare changes from welfare changes in input (output) markets in this way requires two things: (i) knowing demand for either the input or the output and (ii) a known production relationship between the input and output. The information provided by market exchange—input or output prices and demand functions—often allows these conditions to be met.[13]

Unfortunately, ecological systems usually lack this information. Typically, neither the ecological inputs nor the outputs are market goods and thus are not priced. This has important implications for the focus of valuation activity. If both inputs and outputs are unpriced, should the focus of nonmarket valuation be on inputs, on outputs, or on both? Given that welfare measures can be derived from knowledge of production functions and either input or output demand, does it matter which is the focus in nonmarket valuation studies?

Implications of a Systems Approach for Commodity Definition and Interpretation

By our definition, outputs become endpoints when they take on direct meaning to people's utility. How do things take on such direct meaning? This is an issue for cognitive psychology as much as for nonmarket economics (*International Journal of Psychology* 2005). The psychological issues surrounding mental constructions of utility-meaningful environmental commodities is beyond this discussion's scope.

Every respondent comes to a survey with unknown but potentially discoverable degrees of ecological experience and knowledge as backdrops to their responses. However, respondents' *ex ante* knowledge of nature is often incomplete. For example, one cannot ordinarily experience the "web of life." The production processes implied by the web of life must usually be taught and experienced through outcomes of that process (e.g., biodiversity, abundance). One can hear bird songs, but most people would need education to assign sounds to specific species of birds. Because the stated preference analyst has the opportunity to provide additional information, respondents are often given insights designed by the analyst to improve the valuation exercise. For example, respondents often are provided with resource descriptions, pictures,

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[12] Accounting theory is relevant because economic accounts, with gross domestic product being the most visible example, force economists to define the goods and services that are included and excluded in the accounts. For more on the relationship between macroeconomic accounts and environmental valuation, see Boyd (2006) and Banzhaf and Boyd (2012).

[13] As noted by Just, Hueth, and Schmitz (2004), though, "the possibilities for this approach depend on identification of the effects of the relevant nonprice changes on the supply or demand of some essential output or input" (p. 66).

and stories to augment their *ex ante* experience with the resource. Of course, this opportunity to communicate and educate comes with a responsibility not to inject bias. The trick is to inform without manipulating preferences, either consciously or unconsciously.[14]

Process Intuitions, Information, and Education in Surveys

What light does ecological production theory shed on respondent training and its potential to influence elicited valuations? We see both danger and opportunity. In this section, we use production theory to raise concerns about elicited values and their interpretation. In the next section, we propose ways that ecological production theory can be used, in principle, to standardize, empirically experiment with, and improve elicited values.

We now explore the role of real but vague respondent beliefs about ecological production. We begin with a simple example that presumes no information treatments by the analyst. Consider the wetland example associated with Figure 3. If respondents are faced with a stated preference exercise in which they must assess the value of the wetland, what cognitive issues might they face?

Assume the respondents enjoy open space, clean water for swimming, and blue crabs (the endpoints assumed by the example). Now consider three alternative assumptions about the respondents' knowledge and assume that there are no introductory questions in the survey to discover that knowledge.[15]

1. They know nothing about wetland processes and wetlands' ability to purify water.
2. They know wetlands help purify water but not that this is good for the crab population.
3. They know wetlands are good for water quality and that good water quality is good for crab abundance.

Now imagine that respondents are asked about their WTP to preserve this wetland.[16] How should we interpret a positive wetland valuation received from a respondent? Under the first informational assumption, the expressed value reflects only the direct amenity (open space) benefit associated with the wetland. If the valuation is subsequently used in a policy or other decision-making context, interpretation of the derived value should be that it is narrow and reflects only one particular social benefit associated with the wetland.

[14] See Schkade and Payne (1994, p. 105): "An obvious hypothesis, for which there is some support, is that the more ambiguity in one's preferences . . . the more one's expressed preferences will be subject to procedural and descriptive influences."

[15] It is common practice to ask certain introductory questions in a stated preference survey about prior knowledge of the ecosystem of concern, such as whether the respondent has visited the site and, if so, what types of recreation they enjoy. It is not common to ask about prior knowledge of ecosystem processes, inputs, and outputs. Banzhaf et al. (2006) asked people if they understood the concept "web of life" but did not probe more deeply than that. Note, though, that many questions about prior knowledge of science and perceptions and preferences are probed in focus groups to inform survey design and compare the study population to the general population.

[16] We recognize that this might not be the exact type of question asked. Instead, respondents might be asked about the value of a particular type of improvement to a wetland.

Under the second information assumption, the expressed value reflects not only the open space value (as previously noted) but also the value of clean water and the wetland's marginal contribution to it via a perceived production function. In one sense, this valuation is better in that it more comprehensively captures the wetland's value to the respondents since it includes the wetland's role in producing benefits associated with improved water quality. On the other hand, the valuation introduces a potentially important source of cognitive difficulty and error. If subjects know that there is a relationship between wetlands and water quality, they will naturally make assumptions about that relationship. Unfortunately, an accurate assessment of the wetlands' value as an input to water quality requires a vast amount of information and expertise. What nutrient loads are present and what is the wetland's ability to sequester or convert them? Even if demand for water quality can be accurately elicited from the respondent, the wetland valuation associated with the benefits will tend to be a wild guess. More precise properties of the intervening production function are unknowable to nonexperts.

The third information assumption is similar but introduces an additional production process and thus an additional source of cognitive difficulty and error. Respondents must undertake a second translation—from water quality to crab abundance—that compounds the cognitive challenge they face. Again, the resulting valuation is better in that it more comprehensively reflects the benefits derived from the wetland, but it doubles down on the biophysical expertise necessary to arrive at an accurate valuation (even if demand for crabs is clearly expressible by respondents).

Also, interpretation of expressed wetland values by a policymaker depends on which information assumption holds. If all respondents fall in category 1, this may be good news since the elicited WTP values will not include inaccurate value inferences associated with subsequent biophysical production (clean water and crabs). The bad news, of course, is that only the narrow amenity value of the wetland is being expressed and thus the wetland's full value is not captured.

On the other hand, if respondents fall under categories 2 and 3, the results should be interpreted as reflecting potentially large amounts of error associated with only vague knowledge of related production functions. From a systems viewpoint, the cognitive demands placed on subjects asked to value input-based commodities get too little attention, particularly when it is time to interpret the meaning of an elicited WTP value.

Which informational assumption is most likely to be true in the population? We conjecture, and there is some empirical evidence (certainly from focus groups we have done and from polling results), that people generally know that ecological commodities are connected via biophysical processes. For example, Blomquist and Whitehead (1998) examined elicited WTP values for wetlands and found that values were significantly influenced by the ways in which wetland services were described. This can be explained in part by how the descriptions trigger ecological-production-related intuitions about value. As Blomquist and Whitehead concluded, "One implication for [contingent valuation] research is that detailed characteristics and service information are important components of contingent market design. This is especially true for heterogeneous environmental resources such as wetlands which may generate WTP statements from resource nonusers who have little personal experience and prior information about the resource" (p. 193).

We note that many school curriculums feature basic ecosystem units that can be effective in creating ecological production intuitions—intuitions reinforced by time spent hunting or fishing. Accordingly, many people will *want* to assign values derived from biophysical processes. The valuation problem is that these process *intuitions*, while potentially real and qualitatively accurate, are unlikely to be quantitatively accurate.[17]

Now consider a study that includes information treatments designed to educate respondents and fill in gaps in their *ex ante* knowledge of the resources in question. We hypothesize, but leave to empirical verification, that information treatments tend to trigger intuitions about interlinked ecological production processes. In other words, the more subjects know about nature, the more they are likely to see it as a system of production. This will tend to convert respondents into subjects more like those associated with the third information assumption. As noted earlier, this is not necessarily a good thing. Greater understanding of production relationships helps people qualitatively comprehend the production system. But that same understanding complicates the cognitive challenge and can lead to quantitatively inaccurate valuations (due to respondents' need to estimate biophysical production relationships).[18]

It is not surprising when a respondent assigns positive WTP to an input commodity like habitat since that requires only a single intuition: that habitat is good for a species that is valuable. (And given that the commodity is described as "habitat," how could they not infer that it is good for some species?) It is not even surprising when expressed WTP is found, with statistical significance, to increase with the level of the commodity. All that is required is one other intuition: that there is a monotonic production relationship between the input and an output intuited to be valuable. These intuitions may be real and accurate, but their effect on the accuracy of demand inferences from elicited WTP responses is worrisome. Also, these intuitions may be a significant source of confusion, discomfort, and ambiguity in the cognitive demand construction process.

To be clear, we also see opportunity in the clear communication of ecological production processes as a way to improve valuations by focusing respondents on commodities about which they care. Consider Adamowicz et al. (1998), which, in an information treatment, provided respondents with the level of caribou that was "sustainable." Population sustainability is a process phenomenon that links abundance levels to a species' ability to maintain that abundance. With the sustainable level identified by the researchers, WTP for additional caribou was found to reach a threshold that corresponded to the sustainable level: "Respondents indicated that moving to the 'sustainable' level of caribou is quite important but movements beyond this level are not as important" (Adamowicz et al. 1998, p. 74). This result is not surprising in retrospect (as noted by the authors) given the information provided to respondents prior to the valuation.[19] Had the information on sustainable population numbers not been

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[17] This is closely related to the "problem" of expansive priors (Ajzen, Brown, and Rosenthal 1996). Also see Banzhaf et al. (2006, p. 449): "We discovered in focus groups that when we omitted mention of forests and birds, respondents substitute their own 'expansive priors,' ascribing much broader and larger harms, and, subsequently, improvements to these attributes than we intended."

[18] In the next section, we propose that production theory be used to educate respondents but that this education take a particular form designed to eliminate confusion between inputs requiring process knowledge and endpoints that do not.

[19] The authors "suspect that the nonlinear shape of the utility of caribou is due to the background information provided to respondents" (Adamowicz et al. 1998, p. 73).

given, elicited values likely would not have featured such a close relationship between marginal WTP and the sustainable population since most respondents would not be privy to knowledge of sustainable levels. The example shows how a particular kind of ecological production information was absorbed and processed by respondents with a clear effect on valuations. Of course, just because information affects WTP does not mean the information is desirable. After all, the information could be a source of bias. However, in this case, the treatment changed WTP in a way that is more plausibly accurate.

As an aside, we note that experts in biophysical production relationships need not be professional scientists. The accumulated experience of farmers, for example, allows them to interpret the role of soil quality and the timing of precipitation in production of agricultural yields. Skilled hunters and anglers sometimes can relate biophysical inputs (the presence of food sources or characteristics of nesting areas) to the species endpoints that concern them.[20] One way to define skilled users of nature is that they experience ecological commodities further back in the ecological process system and use that information to their advantage (a certain type of riffle in a stream is meaningful to a skilled angler, for example). In other words, they use a different set of commodities in their home production. This implies that people vary in what they perceive as ecological endpoints. We see no easy way around this heterogeneity in *ex ante* knowledge and simply note its relevance to the commodity definition question.

A Sample of Commodities Used in the Literature

How do commodities actually used by analysts in the literature compare to the commodities identified by a systems approach to ecological production? Here we describe and interpret a sample of 70 recently published stated preference studies to illustrate the relationship of current practice to the implications of the systems model previously described[21] (see Boyd and Krupnick (2009) for more detail on this literature).[22] Most (53) used aquatic commodities in aquatic ecosystems; 24 depicted terrestrial commodities and 10 addressed wetland commodities.

Several caveats are important at the outset. First, a broad reading of the literature makes clear that there is no standardized way to define commodities suitable for valuation or for subsequent interpretation of derived values. This is due in large part to the complexity of natural systems, the difficulty of designing

[20] In general, however, average respondents have much less experience with such production relationships.

[21] Note that this literature review was performed several years ago and a number of important and relevant studies have been done since that time, including Johnston et al. (this volume), which also recognizes the problems associated with defining ecosystems according to a mix of intermediate and final endpoints. The empirical point of the Johnston paper, however, is a bit different: to "infer respondents' speculations when a final ecosystem service is omitted [from the choice experiment]".

[22] The database was created by searching existing databases, including AgEcon Search, Agricola, Beneficial Use Value Database (BUVD), BioOne, CSA Illumina, EconLit, Environmental Valuation Reference Inventory (EVRI), GeoRef, Google Scholar, SciSearch/Science Citation Index (Web of Science), SCOPUS, Sportfishing Values Database, and SSRN. We also searched the internet, journals, our own files, files of Abt Associates, and other relevant sources. In addition, we reviewed eight meta-analyses: Van Houtven, Powers, and Pattanayak (2007), Wilson and Carpenter (1999), Brouwer et al. (1999), Kramer, Holmes, and Haefel (2003), Nunes and van den Bergh (2001), Abt Associates (2008), Johnston, Besedin, and Ranson (2006), and Woodward and Wui (2001).

surveys when the psychology and cognition of environmental systems and outputs is poorly understood, and the studies' varying objectives. For example, the purpose of many stated preference studies is to address theoretical and methodological issues rather than derive policy-relevant values.

Systems Thinking in the Valuation Literature

A systems approach to commodity choice, decomposition, and interpretation of valuation estimates is rare in the literature. We queried the inventory of studies that defined startpoints in terms of ecosystem outputs and that explicitly linked them to underlying ecosystem processes or inputs. Only 15 of the 70 studies displayed any kind of systems intuition. We recognize that other studies have done so within the design and focus-group stages, but it is not evident from the published literature.

Indeed, several published studies have noted the importance and difficulty of such systematic interpretations but then leave aside the issue as one for further inquiry. For example, in a meta-analysis of wetland stated preference valuations, Brouwer et al. (1999, p. 25) noted that "wetland ecosystem structures and processes provide various wetland functions. These are highly interrelated, making it very hard, and in some cases impossible, to distinguish between individual functions . . . With some effort, we managed to come up with an arbitrary distinction between these environmental value components and wetland functions by splitting them up into indicator variables which were subsequently used in a quantitative meta-analysis of the [contingent valuation] wetland studies." Like our analysis, the meta-analytic literature reveals the difficulty of comparing the results of primary valuation studies due to a lack of uniformity in or protocols for commodity definition. The heroic efforts made in this literature (Van Houtven, Powers, and Pattanayak 2007, Brouwer et al. 1999) to convert diverse commodities into *ex post* comparable units clearly illustrate the issues.[23] See also Holmes et al. (2004, p. 29), which noted that "among the greatest challenges facing ecological economists is the ability to discern and articulate the linkages between ecosystem science and the things people value."

We found a wide range of commodities in the 70 studies examined.[24] Some included water-quality measures or levels of pollution concentrations in the water. Those tended to be input-like commodities, but they often were paired with output-like commodities as well. For example, ten studies used the water-quality ladder, which can be thought of as a way to translate inputs (numeric measures of water quality) into endpoint-like outputs (fishable water or swimmable water).

Other common types of commodities are measures of some physical resource quantity (e.g., acres of habitat or flow rates).[25] Twenty-nine studies relied on

[23] As an example, Van Houtven, Powers, and Pattanayak (2007) conducted a meta-analysis of 18 studies that offered varying definitions of water quality as the commodity to be valued. The authors constructed a ten-point water-quality index and adapted each study to it. They noted that their conversion of commodities into the ten-point metric inevitably involved "subjective judgments and uncertainties." Also, they had to exclude several other studies because they were unable to map the primary studies' commodities into their ten-point scale.

[24] Not reviewed because it had not been published yet was Johnston et al. (2007), which used an ecosystem health index.

[25] Many of these commodities can be both inputs and outputs. Flow rates, for example, are end products from the standpoint of rafters and kayakers but inputs to habitat and species protection.

these types of commodities. For example, Brown and Duffield (1995) defined their commodity as in-stream flow. The survey described "problems associated with low flows, and the possible benefits if flows were increased." The WTP question asked if the respondent would purchase an annual membership in a trust fund to buy water when needed to avoid damaging low flows in the river. As another example, Messonnier et al. (2000) defined their commodity as aquatic plant coverage of a lake's surface area. Plant coverage affects recreation activities (less is better). The questionnaire included five aquatic plant control alternatives under which plant coverage of the lake varied. Milon and Scrogin (2005) is an interesting study because it tested the difference in WTP between an input and an output (in our language). The sample was split so that half the respondents received a survey that characterized improvements to the Everglades through, in our language, dual commodities (water levels and timing). The other half received a survey that characterized improvements through a particular output of the system (species populations). The difference in resulting WTP was significant with the former treatment yielding a smaller WTP. This difference is not surprising given a systems view of the commodities in question. First, there are real differences between the commodities used in the two treatments. Second, differences are to be expected since there is no reason an input and its associated output would have the same value.

The other 34 studies used biological indicators and 7 used catch rates.[26] In general, we found systems thinking to be rare in the definition and communication of commodities used in those studies. We also found a great deal of heterogeneity in commodities used. This is not a problem per se and is understandable given nature's many attributes, but it does pose problems for interpretation of values by the users of WTP studies. We now turn to our major concern with commodities observed in the literature, one due in large part to a lack of systems thinking: the dual nature of ecological commodities, which are *both* endpoints and inputs to subsequent biophysical production.

Use of Dual Commodities

As noted earlier, many ecological commodities are dual in nature; that is, they are both endpoints and inputs to subsequent biophysical processes. The dual nature of commodities triggers a set of cognitive and valuation issues.

Blamey, Louviere, and Bennett (2001, p. 154) made what we believe is a helpful and pertinent observation: "inclusion of causally related attributes may encourage some respondents to try to understand the causal relations among attributes to assign greater meaning to alternatives and, potentially, simplify their decision making process. Should this occur, there may be implications for the weights assigned to each attribute, and in turn the marginal WTP for the attributes and/or welfare estimates . . . Future research designed to isolate and determine the locus of any such effects as well as their generality would be beneficial."

Holmes and Adamowicz (2003, p. 183) made a similar point: "attributes encountered in environmental valuation problems may be highly correlated by natural processes and, thus, they are not intrinsically separable. If two correlated attributes were treated as independent in a valuation experiment,

[26] Catch rates are not a purely biophysical commodity since they are a function of the technology and practices used to catch fish. However, they are a signal closely correlated with underlying fish abundance.

respondents might become confused, reject the scenario, and fail to answer the question . . . In general, the problem of correlated attributes is best solved by selecting attributes that represent separable dimensions of the valuation problem." If the presence of an endpoint that is independently valuable also affects the provision of a second commodity, respondents may, as suggested by Holmes and Adamowicz, be confused by the commodity's dual nature.

Another cognitive issue associated with a dual output is that a change in its level can have conflicting implications for welfare. Consider a commodity like "water clarity." As an endpoint relevant to aesthetic benefits, greater water clarity is always better. However, water clarity is not always better for species abundance. In fact, the clearest waters are often the most biologically barren. If so, the subject may have to approach the commodity as being both good *and* bad. This kind of scenario may lead to confusion or rejection of the scenario by some respondents.

Also, particularly knowledgeable subjects might intuit that inputs and dual commodities are often nonmonotonic in their relationship to welfare. Nutrients in surface waters are an example. Up to a point, nutrients are desirable for species abundance, but at some point they become detrimental. This is yet another possible way in which technical, non-endpoint commodities can confuse subjects.

There is an additional problem with the presentation of dual commodities. By definition, dual commodities imply correlation issues. A dual commodity's level affects the production of a second, distinct commodity. The presentation of dual commodities is common in the literature. Table 3 provides some examples of attributes presented to respondents in the studies cited.

Table 3

Loomis et al. (2000) • Diluted wastewater • Naturally purified wastewater • Reduced erosion • Habitat for fish and wildlife	**Johnston et al. (2002)** • Farm land • Undeveloped land • Wetlands • Shell fishing areas • Eelgrass
Banzhaf et al. (2006) • Sugar maple, red spruce, and white ash • Forest stands • Songbirds • Aquatic birds	**Blomquist and Whitehead (1998)** • Percent of year wetland is flooded • Number of species present • Degree of flood control • Water quality improvement
Adamowicz et al. (1998) • Mountain caribou population • Wilderness area	**Holmes et al. (2004)** • Game fish • Water clarity • Wildlife habitat • Allowable water uses • Index of ecosystem naturalness

In each of these examples, at least one of the commodities is dual in nature. Not only that, the dual commodity is an input to a subsequent process affecting another commodity used in the study.

Specifically, in Loomis et al. "purified and diluted wastewater" is both an endpoint (water quality) and an input to "habitat for fish and wildlife." In Johnston et al., "wetlands" are a possible ecological input to "shellfishing areas" and "eelgrass" (also "wetlands" are a subset of "undeveloped land"). In Krupnick et al., "tree abundance and health" is an endpoint and can be interpreted as an input (as habitat) to the abundance of bird species. In Blomquist and Whitehead, "percent of year wetland is flooded" and "water quality improvement" are endpoints and, at the same time, unacknowledged (but actual) inputs to "number of species present." In Adamowicz et al., "wilderness area" is an endpoint for purposes of generating bequest and existence benefits but seems like it could be an input to the caribou population. In Holmes et al. (2004), "water clarity" is an endpoint relevant to recreational benefits but also, intuitively, is an input to game fish abundance. And wildlife habitat is not an endpoint at all (unless subjects view it as "land cover that is natural open space and thus a contribution to aesthetic, bequest, or recreational benefits") but rather is an input to wildlife abundance (which is not presented as a commodity in the study). Ecosystem naturalness can be considered an input to every other commodity presented in the study—fish, water clarity, habitat, and allowable water uses.

These examples are not exceptional; rather, they illustrate the larger literature. From a systems perspective, and with the hypothesis that subjects have at least some intuition about interconnections between ecological attributes, the examples raise real questions about what exactly the subjects thought they were valuing and the accuracy of valuations given that production functions were embedded in the valuation task.

We emphasize that it is possible that the authors of these studies depicted ecological inter-relationships for respondents and took care to adjust their valuation results accordingly. However, we can claim that the published results give very little information on the role of systems organization, subject training, or the implications for interpretation of the resulting value estimates. In many cases, for example, the survey questionnaires used to define the commodities for respondents are not included in the published literature or otherwise routinely available.

Accordingly, decision-makers who wish to use these studies to guide policy and management should do so with caution. It is often nearly impossible to tell from the published results what specific commodities subjects thought they were valuing, how double-counting was addressed given the dual commodities presented in the experiments, and the value errors that may have been introduced when subjects relied on intuitive but potentially inaccurate production relationships.

Nevertheless, taken as a whole, these concerns tend to favor the use of choice experiments (CEs) over contingent valuation methods because of CEs' greater flexibility in defining, disaggregating, and estimating shadow prices for attributes. The CE approach features decomposition of bundled goods into components for which values, in principle, can be estimated independently. The relevance to our systems approach is that attribute-based methods clarify the separability of commodities. CE methods do not usually explicitly consider the production relationships between components, but they do often highlight statistical issues associated with correlations among attributes.

Table 4

Gordon, Chapman, and Blamey (2001) • Improved water flow in some rivers • Improved water flow in all rivers	**Sanders, Walsh, and Loomis (1990)** • Protection of an incremental number of rivers
Holmes and Kramer (1995) • Protection of spruce-fir forests	**Jenkins, Sullivan, and Amacher (2002)** • Percent of dead spruce-fir forest stands
Kramer and Eisen-Hecht (2002) • Protection of current river basin's water quality relative to degraded future scenario	**Whitehead, Haab, and Huang (2000)** • Improvement in water quality in an estuary • Improved wildlife habitat in an estuary

Massively Dual Compound Commodities

Not only are the preceding examples illustrative of the larger literature, they are in fact exemplary in that they attempt, to some degree, to disaggregate the environmental commodity. Even more problematic from a systems perspective are studies that present subjects with highly general, or compound, commodities. Compound commodities, from a systems perspective, are particularly likely to be "massively dual" in nature. That is, they not only are bundles of endpoints but are bundles of inputs to subsequent production of beneficial endpoints. As examples, consider the commodities presented to respondents in the studies cited in Table 4.

These examples highlight the use of commodities that impose particularly significant cognitive challenges given the high degree of aggregation. Each commodity can be considered individually as an endpoint of direct relevance to home production. Certainly, households care about river flows because they are important to recreational boating, protection of river systems because of existence and stewardship benefits, and undamaged forests for aesthetic reasons. But all of these commodities also provide a range of inputs to subsequent biophysical production: river flows affect irrigation, soil quality, sediment loadings, and flood probabilities; water quality affects species abundance with existence, recreational, and commercial benefits; and standing forest damage can be a signal of habitat loss (with subsequent species effects) and changes in water runoff and fire behavior. If the commodity is not unbundled (decomposed) for the respondent, valuations require respondents to estimate the magnitudes of a whole suite of processes and ultimate outputs.[27]

Compound commodities like these multiply the valuation and interpretation problems discussed earlier. Given even vague systems intuitions on the part of respondents, what exactly do they think they are valuing? What role do

[27] The distinction between outputs and inputs sheds an interesting light on the so-called embedding problem—a collection of cognitive issues known to cause uncertainty in stated preference experiments. Embedding can be thought of as inclusion of information, values, or predictions extraneous to the object of the valuation. The unbundling of input bundles (like habitat or forest) into a set of distinct, associated outputs and the focus on outputs as the commodities to be valued is a way of depicting many of the relationships likely to be embedded in perceptions and value estimates.

production relationships play in the values elicited from respondents? And how should the resulting valuations be interpreted?

We note again that studies may feature systematic input, output, and production information within the experiment itself. But in published format the literature offers little or no insight into how these issues were dealt with in the design and execution of the studies.

How Disaggregated Should Endpoints Be?

The preceding discussion raises a question. How decomposed should commodities used in stated preference studies be? The simple answer is that decomposition is desirable if firms and households think it matters to their utility.

Endpoints can be presented to respondents in varying degrees of detail. For example, consider a survey that asks people to place a value on "acres of viewable open space." This is a legitimate endpoint associated with visual amenity benefits that may be enjoyed by recreationists and homeowners. In other words, consumers can be expected to place a value on open space since they are familiar with that commodity's role in their well-being. However, "open space" is a very general commodity. A less general commodity is "forested open space." Less general still would be "coniferous forested open space." Is "open space" a single commodity or should it be disaggregated into subsets of commodities differentiated by the type of land cover? We refer to undifferentiated commodities as aggregated commodities and differentiated commodities as disaggregated commodities.

As a rule, disaggregation is better since it means more information about the commodity is provided. Often, endpoints will be context-dependent and different contexts refer to different populations enjoying the endpoint or enjoying it at different locations and times. Disaggregation fosters our ability to detect context-dependence. Also, more differentiation helps avoid problems associated with what are called "expansive priors."[28] Expansive priors are unstated assumptions or views of a commodity that can bias valuations. For example, open space may be interpreted by some people as farm land and by others as parks and forest. Disaggregating open space into farm land and forest will yield more useful valuation estimates because there will be greater clarity on the part of respondents and analysts about the precise commodity in question. The decomposition of environmental commodities into finer-grained endpoints is a function of whether detail is considered important to firm and household production. The corollary to this is that commodity decomposition is not always necessary.

Disaggregation can be carried to an extreme. When people are asked whether they care about something, such as which specific species are protected, they often report that they do not care about that level of detail. Returning to the open-space example, it is entirely possible that people do not differentiate between coniferous and deciduous forest cover when it comes to visual amenities. If so, aggregation into a more general endpoint like acres of forested open space is legitimate. Another example where aggregation may be legitimate is valuation of avoided extinctions. It is even possible—though it is an empirical

[28] See Banzhaf et al. (2006) for a discussion in the context of their stated preference study of ecological improvements in the Adirondacks. Another remedy to expansive priors is to call out and then dismiss some particular input, process, or output of concern to the respondent.

question—that people care generically about extinctions and less so about the extinction of specific species.[29]

We emphasize, though, that disaggregation is often most pertinent to valuations. Trout anglers are specifically interested in trout populations, so endpoint aggregation into fish populations is undesirable when it comes to valuations of angling benefit. Similarly, many birders will want to know about specific species populations, not just bird populations.

Commodity disaggregation also can be important when people explicitly place value on what can be called "compound endpoints." These are bundles of endpoints for which there is complementarity between specific, meaningful features. Again, consider visual amenity benefits associated with open space. There is empirical evidence that people prefer to see open space that is a mixture of forest and pasture to a landscape composed entirely of forest or pasture (Bastian et al. 2002).[30] In that case, the commodity definition should explicitly reflect the mixture of land cover types.

Temporal detail—the precise time at which an endpoint is present or absent—also can be important to some valuations. Consider water volumes. To boaters, the timing of water flow is extremely important. Annual water flow is far less informative than summer water flow, for example. And farmers clearly care deeply about the time of year when surface or aquifer irrigation water is available. Finally, spatial detail often is important. We turn to that issue in more detail in the next subsection.

Spatial Endpoint Modifiers: Scarcity, Substitutes, and Complements

A distinctive feature of many ecological commodities is that the commodities are not transportable. This has important implications for valuation. The effect of neighborhood features on values tends to be pronounced. The realtor's mantra "location, location, location" reflects the strong dependence of real estate value on neighborhood.[31] In the same way, ecological commodity values are strongly dependent on location. The social value of New York's Central Park is clearly related to the proximity of thousands of households, for example.

Several general spatial or "neighborhood" features are important to a consumer's valuation of ecological endpoints. First, how geographically scarce is the endpoint? All else being equal, a given site-specific endpoint will be more valuable if it is spatially scarce rather than abundant. Second, are there substitutes for the endpoint? Again, an endpoint will be more valuable if substitutes for it are spatially scarce rather than abundant. Consider a bass population in a particular lake. As a rule, the value of this endpoint to anglers depends not only on the endpoint itself but also on the presence of other nearby lakes with bass populations. The value also may depend on the presence of nearby substitutes for bass fishing, such as streams with abundant trout. To take another example, the value of surface water available for irrigation depends on the availability (and hence location) of subsurface water.

Third, is the endpoint accompanied by complementary features? The value of many ecological endpoints depends on the presence of complementary inputs.

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[29] It is likely that people care about the extinction of specific charismatic species (polar bears, bald eagles). However, they may not care about specific insect extinctions.

[30] The study found that "view diversity, rather than uniformity, is highly valued" (p. 345).

[31] Wetlands, for example, have been found to increase the value of homes in urban areas (Mahan, Polasky, and Adams 2000) but lower them in rural areas (Bin and Polasky 2005).

Consider again the value to anglers of a bass population in a given lake. That value is a function of access to the lake. Are there docks and boat ramps? If not, the angling value may be limited. Again, neighborhood characteristics often matter to valuations.

Ideally, WTP studies should clearly explore the role of these factors in elicited WTP and report their effects. In other words, spatial modifiers that explicitly depict the scarcity of, substitutes for, and complements to the endpoint in question should accompany endpoints.

Because location matters to the value of specific ecological endpoints, researchers must take special care to isolate the effects of scarcity, substitutes, and complements on the valuations they receive from respondents. While few studies have addressed presentation of spatial information this thoroughly, the analysts who did have highlighted the sensitivity of valuations to spatial factors (Johnston, Swallow, and Bauer 2002).[32] The generic concern again is with embedded priors. When presented with a commodity, consumers may have idiosyncratic latent beliefs about its scarcity or may make inappropriate implicit assumptions about the presence of complements and substitutes.

Few of the studies in our database explicitly referenced substitutes and complements for affected resources that were situated outside the resource or area in question, though there are exceptions. For example, Damery and Allen (2004) administered a survey on shellfishing that asked respondents for their WTP for a shellfish permit or willingness to accept (WTA) giving up a current permit. Before asking the WTA question, the survey reminded respondents that "if you choose to surrender a permit you already own, you will be unable to shellfish in any other town for the duration of the year." Here, the substitute is the ability to shellfish in another location (town).

Another example is Brown and Duffield (1995), which tested how WTP is affected by information on substitutes. The study asked separate samples about WTP to protect in-stream flow in one of five Montana rivers. In effect, the five-river treatment presented information on the availability of substitutes while the single-river treatment did not. Respondents who received information on substitutes (the five-river example) were willing to pay half as much for a given flow protection program as respondents who did not receive that information (the single-river sample).[33]

As for complements, an example is Vossler and Kerkvliet (2003), which proposed a riverbank stabilization and improvement program. Proposed improvements include plazas, a multi-modal path, lighting, street improvements, parking, and using stones and vegetation to restore the riverbank and provide enhanced riparian and aquatic habitat. Here, the development could be seen as a complement to the riverbank environment by providing greater access to the river and, for some, a more inviting overall experience.

[32] "Stated preference models rarely incorporate spatial attributes, or address spatial patterns in associated econometrics. Such omissions may be particularly troubling in cases where the survey instrument itself provides cartographic details that respondents may associate with particular spatial characteristics" (Johnston, Swallow, and Bauer 2002, p. 481).

[33] Revealed preference studies that employ spatial modifiers to explain WTP differences include Bastian et al. (2002), Schlapfer and Hanley (2003), and Cho, Poudyal, and Roberts (2008).

Implications of Ecological Systems Thinking for Valuation Studies

Our review of the literature suggests that stated preference studies should more clearly report how they choose and describe environmental commodities both in pre-testing and in the survey itself. Approximately half the studies we reviewed did not provide details on pre-testing protocols and the ways in which environmental commodities or systems were described. Twenty-five of the 70 studies sampled did not even provide the WTP question in the published article. For the vast majority of studies, it was nearly impossible to understand what ecological production information (if any) was given to respondents. In general, we found little evidence of commodity definition that was driven by clear economic or biophysical principles. We hope that our discussion will contribute to a more concerted debate about what those principles should be.

We also argue that the commodities used in such studies, apart from being poorly described and wildly heterogeneous, are often far from the prescriptions offered by our approach. The lack of an ecological production or "systems" mindset raises a set of concerns about elicited WTP values. First, production theory highlights cognitive issues likely to be confronted by respondents, issues that can lead to scenario rejection, confusion, and bias. Second, production theory identifies how value errors are likely to be introduced by a commodity, triggering respondents' intuitions about subsequent biophysical production. For example, non-endpoint commodities require subjects to estimate biophysical production relationships in ways likely to introduce error, and the error is unlikely to be systematic across the respondent population. Third, production theory is needed for interpretation of WTP estimates to identify clearly the commodities leading to WTP and to sort out possible double-counting of benefits. The dual nature of many ecological commodities complicates the respondent's cognitive challenge and/or the analyst's interpretation of the elicited values.

The flipside of these concerns, though, is that they suggest an intriguing set of research questions and recommendations for the improved use and interpretation of valuation studies.

Research Questions for Future Stated Preference Studies

Our production theory hypothesis is that valuation studies can be improved in a variety of ways by having focus groups and respondents develop and react to simple ecological process "models"[34] designed to illuminate relationships between intermediate and endpoint-type commodities. This hypothesis triggers a number of research questions: Does articulation of ecosystems in this way reduce cognitive errors, confusion, and scenario rejection associated with intuitions about ecological production? What is the effect on valuations of inclusion versus valuations of exclusion of an ecological process model in survey treatments? What is the effect on subjects of presenting endpoints attached to illustrated systems of ecological production versus presenting them without an associated system? Does presentation of process models help overcome subject resistance to disaggregation of bundled commodities?[35] Can

[34] These models do not refer to mathematical models but rather to verbal or visual depictions of environmental inter-relationships, such as those in Figures 1 through 3.

[35] Respondents may not view nature as easily decomposable (Vatn and Bromley 1994). Also, see Brouwer et al. (1999, p. 11): "People seem to enter a [contingent valuation] survey with a

subjects be distinguished based on *ex ante* ecological process intuitions? If so, what is the effect of those intuitions on WTP?[36]

A research strategy to explore these questions would include the following features: (i) research on mental models to explore the degree and type of ecological process intuitions people bring to their perceptions of nature and ecological commodities; (ii) with focus groups, exploration of alternative mental models of ecological production to improve scenario acceptance and design, and (iii) empirical evaluation of alternative ecological production treatments on valuations and their robustness. For example, better performance in scope tests and tighter variances around WTP could be interpreted as evidence that a particular treatment is outperforming alternatives.

Revealed Preference Studies

While our discussion has focused on commodity definition as it pertains to stated preference studies, ecological production is relevant and useful to the design and interpretation of revealed preference studies as well. There is an understandable tendency in revealed preference studies to value what we earlier called aggregated or compound commodities—beaches (Bin et al. 2005); forests, crop land, and pasture (Irwin 2002); wetlands (Mahan, Polasky, and Adams 2000); and open space (Smith, Poulos, and Kim 2002).[37] But a beach, for example, is a collection of endpoint commodities that include water quality, temperatures, wave action, views, sand characteristics, and species populations. When beaches are found to be valuable via revealed preference, interpretation of that value hinges on deeper understanding of what specific endpoints are present and valued.

When revealed preference studies measure specific endpoints, they often reveal that the endpoints matter—they have a statistically significant effect on valuations. Typically, only one or two such qualities are included in a study. But in many cases, examples of what we would call endpoints turn out to matter when they are included. Examples of endpoints found to be valuable in revealed preference studies include the width of beaches (Parsons, Massey, and Tomasi 1999, Massey and Parsons 2002), specific species of fish found in a fishery (Freeman 1995), sand quality—grain size and amount of debris (Murray, Sohngen, and Pendleton 2001), complex and natural forest edges and conifers in rural areas and deciduous species with smoothly trimmed borders in urban areas (Cho, Poudyal, and Roberts 2008), elk habitat (Bastian et al. 2002), and a variety of water-quality features that include clarity and presence of fecal contamination (McConnell and Tseng 1999).[38]

vague holistic value judgment rather than with explicit decomposed value judgments." But our hypothesis is that problems with decomposition may be due to respondents' lack of ecological systems knowledge. If one provides such knowledge (linkages between inputs, processes, and outputs), the decomposition may be more successful.

[36] Another approach would be to assume that the ecological system cannot be clearly communicated and that omitted outcomes will be present. Johnston et al. (this volume) tested an approach to identify statistically "speculations" by respondents regarding such omitted outcomes.

[37] The tendency is understandable because such studies employ real rather than hypothetical data on the environmental commodity. Reviews of the revealed preference literature note the tendency to rely on very general commodity definitions (McConnell and Walls 2005, Freeman 1995).

[38] To be clear, though, greater disaggregation into specific features does not always matter. For example, Mahan, Polasky, and Adams (2000) found that housing prices were influenced by proximity to wetlands but that the type of wetland (open water, forested, scrub-shrub, emergent)

An obvious implication is that revealed preference studies ideally would relate behavior to more specific kinds of environmental commodities. One way to do this is via linked stated and revealed preference studies (Cameron 1992, Eom and Larson 2006, Whitehead, Haab, and Huang 2000) in which the sources of a revealed preference can be identified in greater detail by the stated-preference component. This is desirable for several reasons. First, environmental policy decisions often affect (positively or negatively) specific endpoints rather than more aggregated commodities. For example, policies may be geared toward water-quality improvement or beach replenishment. In the analysis of these policies, we want to know the value of water quality and beach replenishment, but it is difficult to infer these benefits from the "value of beaches."[39] The second reason for greater endpoint specificity is the desire to transfer value estimates from one study site to another. The type, quality, and abundance of specific endpoints can be used to empirically control for within-category differences in a generic commodity type (beaches, forests, parks, and rivers).

A final observation is that ecological production theory can help improve interpretation of revealed preference valuations. For example, consider the truism that revealed preferences capture not the total value of a natural resource but the part revealed by measurable behavior. Ecological production theory can help economists explain the values captured in a given study versus those that are missed. To illustrate, return to the wetland example depicted in Figure 3 and imagine a hedonic analysis that finds a price premium for houses in proximity to the wetland. Are all of the wetland's benefits (those associated with open space, water-quality improvements, and crab abundance) reflected in the hedonic premium? The wetland's open space and other aesthetic features are likely to be perceived and important to nearby homeowners so we would expect to detect the value of those kinds of endpoints in the hedonic analysis. However, the other endpoints associated with the wetland (improved water quality and crab abundance) are less likely to be detected in property prices. First, homebuyers may not know wetlands' role in the production of clean water and crabs. Second, even if they do know, homeowners may themselves not be the beneficiaries of those processes.

A description of the ecological system, including where and how beneficial outcomes are produced and where they are delivered, helps clarify the source of benefits as well as additional benefits that would not likely be detected by a given revealed preference technique.

Benefit Transfers

To judge the relevance of a particular study to a new site, one must know how comparable the sites are. A key to that analysis is comparability between the commodities to which different studies attach value. The less *ad hoc* commodity definitions are, the more likely the literature will produce comparable commodities as the basis for valuations. Policy-relevant benefit transfers urgently need that kind of comparability (Morrison and Bergland 2006). A systems approach to commodity definition could enhance comparability and thereby support the development of benefit-transfer functions.

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did not have a measurable effect on valuations.

[39] See Bin et al. (2005, p. 148): "site quality can be controlled through policy measures. Thus, valuation of changes in site quality is directly applicable to policy analysis."

Benefit transfer is the application of values found in one study to other locations, thus avoiding the need for time-consuming and costly new research. Unfortunately, as others have noted, environmental valuation studies are too heterogeneous in their methods, results, and control variables to make this a simple proposition (Rosenberger and Loomis 2000, Loomis and Rosenberger 2006, Johnston and Duke 2007). Endpoints related via ecological production can help clarify the search for multi-attribute differences in the composition and value of environmental resources. Accordingly, a systems approach to commodity definition could play a useful role in development of choice experiments that support benefit transfers.

Summary

This discussion develops a systems-based approach to ecological valuation that draws on the analogy between production theory in economics and production of valuable outputs by an ecosystem. We argue that a production theory approach to environmental commodities yields a potentially important set of prescriptions for the design of stated preference surveys and the use and interpretation of both stated and revealed preference results.

Overall, our prescription emphasizes more rigor and care in the provision of information about ecological commodities and their inter-relationships. The ecological production perspective emphasizes the decomposition of environmental resources into endpoints as close to home and firm production as possible. However, decomposition is accompanied and disciplined by explicit references to a larger system. When the endpoints are linked to a production system, subjects, analysts, and readers can, in theory, more clearly understand production linkages that are real and qualitatively intuited but also are a source of confusion, error, and misinterpretation.

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