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The Definition and Choice of Environmental Commodities for Nonmarket Valuation

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RESOURCES FOR THE FUTURE

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Abstract

Economic analyses of nature must somehow define the “environmental commodities” to which values are attached. This paper articulates a set of principles to guide the choice and interpretation of nonmarket commodities. We describe how complex natural systems can be decomposed consistent with what can be called “ecological production theory.” Ecological production theory—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 the interpretation, usefulness, and accuracy of benefit estimates derived without reference to ecological production theory.

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

JEL Classification Numbers: Q30, Q51, Q57

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The Definition and Choice of Environmental Commodities for Nonmarket Valuation

James Boyd and Alan Krupnick*

1. Introduction

This paper develops 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. We 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. Ecological production theory also leads to suggestions for new stated preference survey protocols. And benefit transfers will clearly benefit 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 willingness to pay 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

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and what are the relationships between those commodities? Some of the arguments presented below 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're an analyst) is that markets not only yield prices, they 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 nonmarket economists is clarification of the nonmarket commodities that yield utility. Nature presents us with many possible units to choose from. 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. Our hope for this paper is to stimulate debate on ways to make commodity definition clearer and more rigorous. Further, 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.

Another reason to discuss commodity definition is the growing inter-disciplinary ecosystem services movement. Ecosystem services 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 paper is organized as follows. 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. Section 3 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 them through the lens of ecological production theory. In so doing, we identify a number of areas in which production theory can potentially improve the accuracy of surveys, acceptance of scenarios by respondents, and the 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, failure to systematically depict those relationships is a potentially important source of valuation problems.

Section 4 identifies what in our view is the ideal approach to commodity definition—at least according to the theory developed in Sections 2 and 3. This approach features the decomposition of resources into what are akin to the system's "final" ecological commodities. Section 5 discusses how ecological production theory can improve the interpretation of revealed WTP values. When revealed preference studies detect a willingness to pay for nonmarket goods, they do so by observing market behavior, of course. This means that the nonmarket commodity that yields additional willingness to pay can be difficult to identify or interpret. How do economic actors, say recreators or homeowners, decompose the natural world based on their knowledge and experience and what does that imply for the interpretation of observed WTP? We argue that our systems approach can aid the interpretation of revealed preference values by helping to identify the commodities most likely to give rise to revealed nonmarket benefits.

Section 6 relates units commonly measured and reported in the natural sciences to the overall discussion of commodity definition. Section 7 concludes and identifies an empirical research strategy to test the hypotheses developed in the paper.

2. An Ecological Systems Approach to Commodity Definition

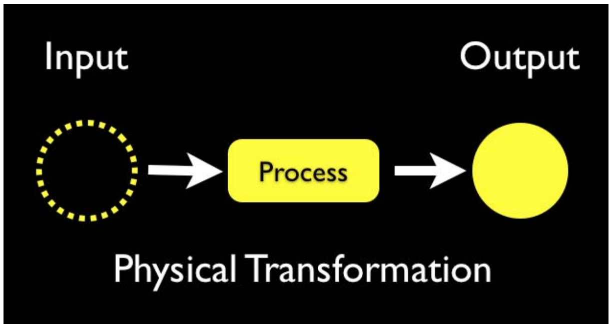
The principles that guide the decomposition and aggregation of nonmarket goods are the subject of this section. Our approach is to describe nonmarket environmental commodities in the context of *systems of ecological production*. We then compare the commodity definition approach suggested by a systems approach to commodities used in the stated preference literature. We find important differences. These differences suggest that a dialogue between a systems approach and empirical practice may be illuminating and help 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 decisionmakers in, for example, a cost-benefit or environmental accounting setting.

2.1 Systems

Nature can be thought of as a complex system, where 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 the 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. Ecological Process or "Production Function"



Ecologists and economists refer to these processes, generically depicted in Figure 1, as biophysical production functions (U.S. EPA 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. These 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.

2.2 Ecological Endpoints Defined

In order 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.[1] Economists refer to what consumers know and make choices about 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 also many nonmarket inputs to household production and utility, including leisure time and ecological commodities. Examples of the latter include open space in their neighborhood, birds at the birdfeeder, and clean water from the well. Likewise, a firm's production process will rely 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 whereas 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 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, nor is it typically the subject of household choice, nor is it tangibly meaningful to most non-experts. But there are direct inputs to home production dependent 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 directly experienced, bear directly on households choices, or 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 in order to make their relevance to utility clear. In other words, dissolved oxygen is not an endpoint because its role in utility requires understanding of its role in production of subsequent biophysical commodities.

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[1] 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 non-experts (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 below.

> **Definition:** Ecological endpoints are meaningful biophysical outputs that do not require expert knowledge of biophysical production functions in order 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 they 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 below.

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	Hydrologic processes	Reductions in flood severity
Urban forest acres	Shading and sequestration	Air quality and temperature
Vegetated riparian border	Erosion processes	Sediment loadings to reservoirs

Consider a firm or household asked to place a value on the commodities on the left-hand 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, they indirectly value lower pH levels. Note though that the value of lower pH must be inferred from two pieces of information (1) the value of the direct fish and bird inputs to household production and (2) 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 and birds requires no further biophysical transformation in order to make its role in household production clear.[2] 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 toy example is as a valuable, but indirectly valuable, commodity.[3]

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 the case of domestic animals and charismatic species (harp seals, for example) or endangered species individual deaths may matter to people.

In other cases, however, individual mortalities may not be the final commodity and thus not ideal for valuation purposes. Consider fish killed by cooling water intakes. To fishermen the fish mortality rate matters because it may change the size of the stock (abundance) of fish and thus will influence the number of fish that can be harvested with a given level of effort.[4] Here, individual mortality statistics require translation via a biophysical production function into changes in the stock. This translation is usually ecologically complex and thus unknowable by households. Accordingly, stock change is the preferred endpoint in such cases.

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[2] 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 bird watching gear.

[3] As we will discuss below, in a more elaborated systems view of wetlands they will play a role as both endpoints *and* inputs to biophysical processes.

[4] Focus groups conducted by Abt Associates found that respondents cared about mortality when the numbers of fish killed were large. The larger the number of mortalities, the clearer the relationship to stock effects will be.

Similarly, eagle or caribou habitat is valuable, but 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).

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, trophic change, etc. Technical outcome measures like these almost always signify the need to subsequently translate the measure into outcomes that are more meaningful to non-technical audiences (i.e., firms and households) in order 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 may be by itself almost meaningless to firms and households; 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.

"Swimmable," "Fishable," and "Boatable" Water Quality

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 objective water quality measures (like dissolved oxygen levels) and their influence on household utility, the water quality ladder was developed to translate numerical criteria into more understandable commodities.[5] Largely because the terms "swimmable," "fishable," and "boatable" were used in the Clean Water Act to differentiate different water quality levels, Mitchell and Carson used these terms as distinct commodities to be valued by respondents. These commodities have a greater resemblance to endpoints than dissolved oxygen levels, since they have greater meaning to households.

But they are clearly vague and, arguably, excessively aggregated. The commodities beg the question: what do swimmable, fishable, and boatable mean in concrete terms? It is notable that in their survey instrument Mitchell and Carson (1989) had to more specifically explain what is meant by these commodities. For example, the

[5] See Johnston et al (1995) who analyze 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," 64).

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." (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, or dying prematurely? Without definition of these more specific public health commodities, respondents are left to their own interpretation of "dangerous."

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 non-experts into non-technical categories like "swimmable," "fishable" and "boatable." Bateman et al (2005,280) created an analogous ladder to relate lake acidity levels into more meaningful commodities (effects on species). They did so 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." They did this because—in our language—pH levels are not meaningful to non-experts.

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. Economists will refer to recreation, flood damages avoided, and aesthetic benefits as ecosystem services. Because the term is used in such different ways we choose to avoid it altogether.

We should emphasize that what people perceive as direct inputs to their home production is a broad and complex empirical and psychological question—an issue we return to in section 3. Our assertion at this juncture is simply that ecological commodities can be distinguished by the degree to which they require understanding of biophysical production relationships in order 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.

The Case of Existence Value

Many people clearly value the existence of certain species. But can threatened species be final commodities given that we may never come in contact with them? Yes, because knowledge of their existence requires no further biophysical translation in order to be relevant to household welfare. The commodity people care about in his case is the species' existence itself. Thus, we can say 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. In order to avoid double counting of value added or social benefits, economic accounts distinguish between intermediate and final goods. For the purposes of Gross Domestic Product accounting, for example, only final goods are tracked and weighted, since the value of inputs is captured in the value of the final product.[6]

2.3 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

[6] Counting inputs and outputs in a single economic index double counts the inputs' role in adding value to the final good. See Dernburg and McDougal (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 GNP total to avoid duplication."

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 will be 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.

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	Hydrologic processes	Flood pulse regulation

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, by a recreator, 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 are also an input to a range of subsequent biophysical production, including species dependent upon the forest as habitat, water filtration and storage, air quality, and sediment reductions.

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 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: how many species are we 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.

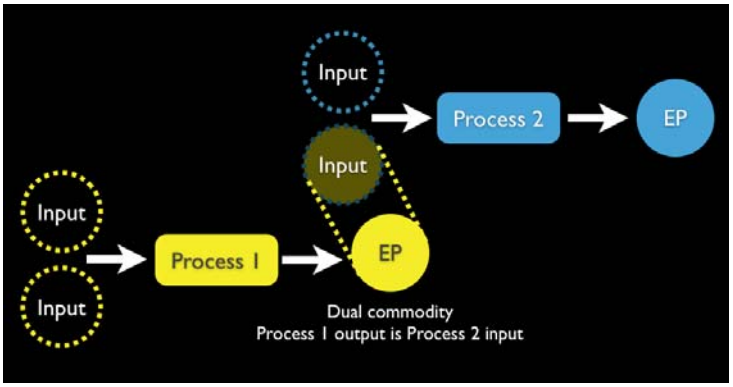
However, biodiversity measures also may be viewed as proxies for the overall health of the ecological system. In this sense, biodiversity is not an endpoint, but rather an intermediate commodity with value as a leading indicator of system conditions. As such, it is not a commodity amenable to household 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 the continued provision of other endpoints. But as a signal of systemic condition, consumers cannot be expected to make the translation of biodiversity measures into subsequent biophysical production of other endpoints they can value. 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 will often be 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 "river," "forest," "open space," and even "wetland" 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 wellbeing.

2.4 Parsimonious Depiction of a System

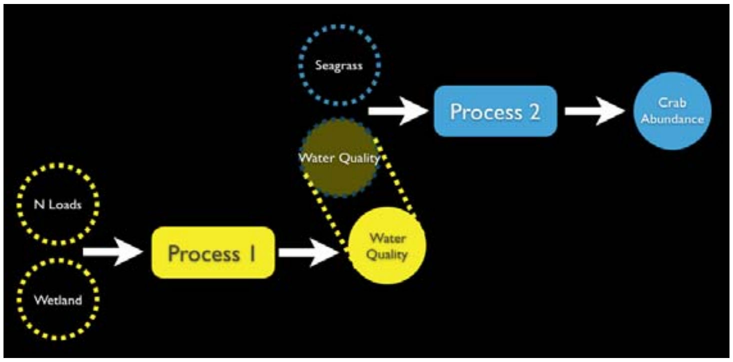
In what follows it is useful to refer to a simple description of an ecological system featuring inputs, outputs, production functions and endpoints. The following figure describes the conversion by one biophysical process of two biophysical inputs into a dual commodity (it is both an endpoint and an input to a second, subsequent biophysical process that yields a second endpoint):

Figure 2. A Simple Production System



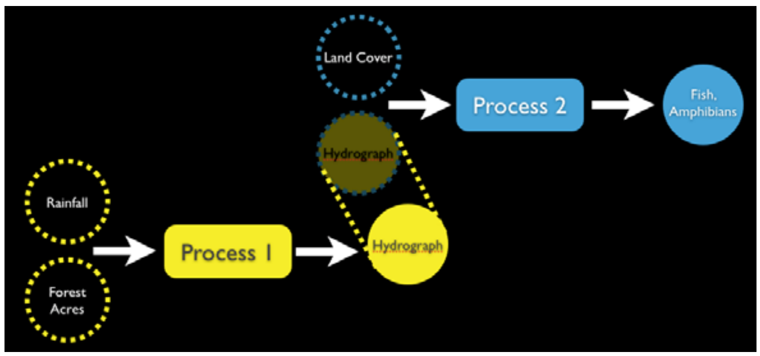
To illustrate the way in which this simple, generic system maps into real examples, consider the following ecologically plausible production relationships linked by commodities that are dual in nature.

Figure 3. Illustration



In the example depicted in Figure 3, wetlands are an input to the production of better water quality. Wetlands—and the hydrological, soil, and chemical processes they embody sequester and convert fertilizer and other nutrients, yielding improved water quality. This improved water quality is an endpoint, since it can be of direct relevance to home production (household aesthetic- and recreation-based welfare 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.

Figure 4. Another Illustration



Or consider a second example, as in Figure 4, where forest cover is an input to hydrologic processes that yield a subsequent surface water hydrograph (the speed, depth, and duration of flood pulses). 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 damages is directly influenced by the hydrograph). In addition, the hydrograph is an input to habitat processes for fish and amphibians whose populations are themselves endpoints.[7]

In our discussion of valuation techniques concepts like bundled ecological commodities and their disaggregation, respondent 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 over-simplified systems such as the above example will help illustrate important valuation issues.

[7] Flooding, like forest fires, can be an important contributor 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.

2.5 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 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 in order to derive the system's value, since that benefit is captured in the surplus generated by factory 2's final output. To include the factor surplus generated by the production of factory's 2'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 GDP as an aggregate measure of consumption weights only final consumer goods and services in order to avoid the double counting that would arise from the inclusion of intermediate goods and service in the index.[8]

In a conventional market setting the analyst may possess detailed information on prices and quantities demanded in both the input and output markets. If so, surplus associated with both inputs and outputs can be measured relatively directly. In other cases, production theory allows 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 et al. 2004, Chapter 4).

Inferring output (input) welfare changes from welfare changes in input (output) markets in this way requires two things: both that (1) demand for either the input or output is known and (2) the production relationship between the input and output is known. The information provided

[8] Accounting theory is relevant because economic accounts, Gross Domestic Product (GDP) being the most visible example, force economists to define the goods and services that are included in the accounts and those that are not. For more on the relationship between macroeconomic accounts and environmental valuation see Boyd (2006, 2008).

by market exchange—input or output prices and demand functions often allows these conditions to be met.[9]

Unfortunately, ecological systems typically lack this information. It is usually the case that both ecological inputs and outputs are not market goods, and thus 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, outputs, or 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 on nonmarket valuation studies?

3. 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.[10] The psychological issues surrounding mental construction of utility-meaningful environmental commodities is beyond this paper's scope.

Every respondent comes to a survey with an unknown—but potentially discoverable—degree of ecological experience and knowledge as a backdrop 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 the 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 thought by the analyst to improve the valuation exercise. For example, respondents will often be provided with resource descriptions, pictures, and stories in order to augment respondents' *ex ante* experience of the resource. Of course, this opportunity to communicate and educate comes with a responsibility

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[9] As noted by Just et al, 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

[10] See International Journal of Psychology, Special Issue (2005).

not to bias. The trick is to inform without manipulating preferences, either consciously or unconsciously.[11]

3.1 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 Section 4 we propose ways in which ecological production theory can—in principle—be used to standardize, empirically experiment with, and potentially 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 a respondent is faced with a stated preference exercise in which they must assess the value of the wetland, what cognitive issues might they face?

Assume the respondent enjoys open space, clean water for swimming, and blue crabs (the endpoints assumed by the example). Now consider three different knowledge assumptions about the respondent and assume that there are no introductory questions in the survey to discover this knowledge.[12]

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.

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[11] 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." The theory is that pictures can evoke a range of in order to avoid to address a possible charge that a pretty picture is manipulating preferences.

[12] 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, if so, what types of recreation they enjoy, and so on. 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," however, but did not probe more deeply than that. Note, though, that many questions about prior knowledge of science, perception and preferences are probed in focus groups to inform survey design and compare the study population to the general population.

3. They know wetlands are good for water quality and that good water quality is good for crab abundance.

Assume respondents are asked in a CV question their WTP to preserve this wetland.[13] How should we interpret a positive wetland valuation received from the respondent?

Under the first informational assumption, the expressed value reflects only the direct amenity (open-space) benefits associated with the wetland. If the valuation is subsequently used in a policy or other decision-making context, the interpretation of the derived value should be that it is narrow, only reflecting one particular social benefit associated with the wetland.

Under the second information assumption, the expressed value reflects not only the open space value (as above) but an additional value: 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 respondent, 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 the subject knows there is relationship between wetlands and water quality they will naturally make an assumption about that relationship. Unfortunately, an accurate assessment of the wetlands' value as 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 these benefits will tend to be a wild guess—given the intervening production function whose more precise properties are unknowable to the non-expert.

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

[13] 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 or improvement to a wetland.

It is also true that the 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 by the valuation.

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 the associated 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 in general know that ecological commodities are connected via biophysical processes. For example, Blomquist and Whitehead (1998) examined the effect on 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 the ways in which those descriptions trigger ecological production-related intuitions about value. As they conclude: "One implication for CV 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."

We note that many school curricula feature basic ecosystems 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.[14]

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

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 will tend to trigger intuitions about interlinked ecological production processes. In other words, the more a subject knows 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 information assumption (3). 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).[15]

It is unsurprising when a respondent assigns a 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 an expressed WTP is found with statistical significance to increase in levels 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 valuation—by focusing respondents on the commodities they care about. Consider Adamowicz (1998, 74), who in an information treatment provided respondents with the level of caribou that is "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 corresponding 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." This result is not surprising in retrospect (as noted by the authors) given the information provided to

[15] In section 4 we will 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 from endpoints that do not.

respondents prior to the valuation.[16] Had the information on sustainable population numbers not been given, elicited values would likely not have featured such a close relationship between marginal WTP and the sustainable population—since most respondents are not 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, WTP changed as a result of the treatment in a way that is plausibly more accurate.

As an aside, we note that experts in biophysical production relationships needn't 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 the production of agricultural yields. Skilled hunters and anglers are also able in some cases to relate biophysical inputs (the presence of food sources or characteristics of nesting areas) to the species endpoints they care about.[17] One way to define a skilled user of nature is that they experience ecological commodities "further back" in the ecological process system and use this information to their advantage (a certain type of riffle in a stream is meaningful to a skilled angler). In other words, they use a different set of commodities in their home production. This implies that people will vary in what they perceive to be ecological endpoints. We see no easy way around this heterogeneity in ex ante knowledge, but simply note its relevance to the commodity definition question.

3.2 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 in order to illustrate the relationship of current practice to the implications of the systems model described above (see

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[16] The authors "suspect that the nonlinear shape of the utility of caribou is due to the background information provided to respondents." p. 73

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

Boyd and Krupnick 2009 for more detail on this literature).[18] Most (53) use aquatic commodities in aquatic ecosystems, while another 24 depict terrestrial commodities and 10 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 nor for the subsequent interpretation of derived values. This is due in large part to the complexity of natural systems, the difficulty of designing surveys when the psychology and cognition of environmental systems and outputs is poorly understood, and because of 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.

3.3 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 on the number of studies that define startpoints in terms of ecosystem outputs and that explicitly link them to underlying ecosystem processes or inputs. Only 15 of the 70 studies display 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 note the importance and difficulty of such systematic interpretations, but then leave the issue as one for further inquiry. For example, in their meta-analysis of wetland stated preference valuations Brouwer et al (1999, 25) note 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 CV wetland

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[18] The database was created by searching the 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, SSRN. We also searched the internet, journals, our own files, those of Abt Associates and other relevant sources. We also reviewed eight meta-analyses, including Van Houtven et al (2007), Wilson and Carpenter (1999), Brouwer et al (1999), Kramer et al (2003), Nunes and van den Bergh (2001), Abt (2006), Johnston et al (2006), and Woodward and Wui (2001).

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 et al. 2007; Brouwer et al. 1999) to convert diverse commodities into *ex post* comparable units clearly illustrate the issue.[19] See also Holmes et al (2004, 29) who note 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."

Of the 70 studies examined, we find a wide range of commodities used. Some studies include water quality measures or levels of pollution concentrations in the water. These tend to be input-like commodities, but they are often paired with output-like commodities as well. For example, ten studies use the water quality ladder, which can be thought of as a way to translate inputs (numeric water quality measures) into endpoint-like outputs ("fishable water," swimmable water").

Other common types commodities are measures of some physical resource quantity (e.g., acres of habitat or flow rates).[20] Twenty-nine studies rely on these types of commodities. For example, Brown and Duffield (1995) define their commodity as instream flow. The survey described "problems associated with low flows, and the possible benefits if flows were increased." The WTP question asks 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) define 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 in which plant coverage of the lake is varied. Milon and Scrogin (2005) is an interesting study because it tests the difference in WTP between an input and 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), and the other half received a survey that characterized

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[19] As an example, Van Houtven et al (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 10-point water quality index and adapted each study to it. The authors note that their conversion of commodities into their 10-point metric inevitably involved "subjective judgments and uncertainties." Also, they were unable to include several other studies because they were unable to map the primary studies' commodities into their 10-point scale.

[20] Not reviewed because it is not published yet, is Johnston et al (2007a), which uses an ecosystem health index. 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.

improvements through a particular “output” of the system (species populations). The difference was found to be significant, with the former treatment yielding lower WTP. This difference is not surprising given a systems view of the commodities in question. First of all, 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 34 studies remaining in our sample use biological indicators and 7 use catch rates.[21] In general, we find systems thinking to be rare in the definition and communication of commodities used in the literature. We also find 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 the interpretation of values by the users of WTP studies. We now turn to our major concern with commodities observed in the literature—and one due in large part to a lack of systems thinking: the dual nature of ecological commodities: commodities that are *both* endpoints and inputs to subsequent biophysical production.

3.4 Use of Dual (Correlated) 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 et al (2001, 154) make 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, 183) make a similar point: that “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, respondents might become confused, reject the scenario, and fail to answer

[21] 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.

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 dual outputs is that changes in their level can have conflicting implications for welfare. Consider a commodity like "water clarity." As an endpoint relevant to aesthetic benefits more 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 may intuit that inputs and dual commodities are often non-monotonic 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. Dual commodities—by definition—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. As examples (by no means exhaustive) consider the following attributes presented to respondents in the studies cited (Table 3):

Table 3. Commodity Examples from the Literature

Loomis et al (2000) Diluted wastewater Naturally purified wastewater Reduced erosion Habitat for fish and wildlife	*Johnston et al (2002)* Farmland 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" are both endpoints (water quality) and inputs to "habitat for fish and wildlife." In Johnston et al, "wetlands" are a possible ecological input to "shell fishing areas" and "eelgrass" (also "wetlands" are a subset of "undeveloped land"). In Krupnick et al, tree abundance and health are an endpoint, and can also 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, "water clarity" is an endpoint relevant to recreational benefits but intuitively, also an input to "game fish" abundance; wildlife habitat isn't 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 an input to wildlife abundance (which is not presented as a commodity in the study); and "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 the interconnections between ecological attributes, the examples raise real questions about what exactly the subjects thought they were valuing and the accuracy of valuations given the production functions 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 the interpretation of the resulting value estimates. In many cases, for example, the survey questionnaires used to define the commodities for respondents are often not included in the published literature, or otherwise routinely available.

Accordingly, decisionmakers 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 dual commodities present in the experiments, or what value errors may have been introduced given subjects' reliance on intuitive but potentially inaccurate production relationships.

Nevertheless, taken as a whole, these concerns tend to favor the use of choice experiments (CE) over CVM because of the greater flexibility in defining, disaggregating and estimating shadow prices for attributes. The CE approach features the decomposition of bundled goods into components whose value can in principle be independently estimated. 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.

3.5 "Massively Dual," Compound Commodities

We emphasize that, not only are the above examples illustrative of the larger literature, they are in fact exemplary in that to some degree they attempt 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 will be not only bundles of endpoints but bundles of inputs to subsequent production of beneficial endpoints.

As examples consider the following commodities presented to respondents in the studies cited (Table 4):

Table 4. "Massively Dual" Commodities Used in the Literature

Gordon et al (2001) Improved water flows in some rivers Improved water flow in all rivers	*Sanders et al (1990)* Protection of an incremental number of rivers
Holmes and Kramer (1995) Protection of spruce-fir forests	*Jenkins et al (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 et al (2000)* Improvement in water quality in an estuary Improved wildlife habitat in an estuary

These examples highlight the use of commodities that impose particularly significant cognitive challenges, given their high degree of aggregation. Each commodity can by itself be considered 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 these commodities also all 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 (and subsequent species effects), 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. [22]

Compound commodities like these multiply the valuation and interpretation problems discussed earlier. Given even vague systems intuitions on the part of respondents, what exactly

[22] 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 the 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.

do they think they are valuing? What role do 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 are dealt with in the design and execution of the studies.

3.6 How Disaggregated Should Endpoints Be?

This 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 recreators 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 wellbeing. 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 general rule, disaggregation is better since it means more information about the commodity is being provided. Often, endpoints will be context-dependent, where different contexts refer to different populations enjoying the endpoint, or 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.” [23] 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 farmland, whereas others interpret it as parks and forest. Disaggregating open space into farmland and

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[23] 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

forest will yield more useful valuation estimates because there will be 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 or not 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 or not they care about things, such as which specific species are protected, they often report that they don't care about this level of detail. And 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 the valuation of avoided extinctions. It is even possible—though it is an empirical question—that people care generically about extinctions, and less so about the extinction of specific species.[24]

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

Another way in which commodity disaggregation can be important is when people explicitly place value on what can be called "compound endpoints." These are bundles of endpoints where 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 with a mixture of forest and pasture to landscape composed entirely of forests or pasture (Bastian et al. 2002).[25] In this case, the commodity definition should explicitly reflect the mixture of land cover types.

Temporal detail is also often very important to some valuations—in other words, the precise time an endpoint is present or absent. Consider water volumes. To boaters, the timing of water flows is extremely important. "Annual water flows" is far less informative than "summer water flows," for example. And clearly, farmers care deeply about the time of year when surface

[24] 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.

[25] The study found that "view diversity, rather than uniformity, is highly valued." 345.

or aquifer irrigation waters are available. Finally, spatial detail will often be very important to valuations. We turn to that issue in more detail in the next subsection.

3.7 Spatial Endpoint Modifiers: Scarcity, Substitutes, Complements

A distinctive feature of many ecological commodities is that they are not transportable. This has important implications for valuation. The effect on values of neighborhood features tends to be pronounced. The realtor's mantra "location, location, location" reflects the strong dependence of real estate value on neighborhood.[26] 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 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 general rule, the value of this endpoint to anglers is not just dependent on the endpoint itself, but also on the presence of other nearby lakes with bass populations. The value may also depend on the presence of nearby substitutes for bass fishing, like 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. 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, endpoints should be accompanied by spatial modifiers that explicitly depict the scarcity of, substitutes for, and complements to the endpoint in question.

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

Because location matters to the value of specific ecological endpoints, surveys need to take special care to isolate the effects of scarcity, substitutes, and complements on the valuations they receive from respondents. While not many studies have addressed this thoroughly the presentation of spatial information, those that have highlight the sensitivity of valuations to spatial factors (Johnston et al. 2002b).[27] The generic concern is again 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.

In our database, few studies explicitly reference the substitutes and complements for affected resources that lie outside the resource or area in question, though there are exceptions. For example, Damery and Allen (2004) administered a survey on shell fishing that asks respondents for their WTP for a shellfish permit or WTA to give up a current permit. Before asking the WTA question, the survey reminds them 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) who test how WTP is affected by information on substitutes. The study asked separate samples about their WTP to protect instream flow in either one or five Montana rivers. In effect, the five-river treatment presents information on the availability of substitutes, while the single-river treatment does 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 this information (the single-river sample).[28]

As for complements, an example is Vossler and Kerkvliet (2003) which proposes a riverbank stabilization and improvement program. Proposed improvements include plazas, a multi-modal path, lighting, street improvements, parking, and using stone and vegetation to restore the riverbank and provide enhanced riparian and aquatic habitat. Here, this development

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[27] "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." p. 481.

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

can be seen as a complement to the riverbank environment by providing greater access to the river and, for some, a more inviting overall experience.

3.8 Summary of the Stated Preference Literature

The stated preference literature is very heterogeneous in its definitions of commodities relevant to nonmarket valuation. Some studies use commodity definitions and information treatments consistent with the production system approach advocated by this paper, but most do not. We found a number of studies that highlight the desirability of systems thinking, but more are needed. Our overall conclusion is that the lack of an ecological production mindset in stated preference studies raises—in theory—a range 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 ways in which value errors are likely to be introduced by commodities that trigger intuitions about subsequent biophysical production. Third, the interpretation of WTP estimates requires production theory in order to clearly identify the commodities leading to WTP and in order to sort out the possible double-counting of benefits.

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 the development of choice experiments that support benefits transfer, as in Johnston 2007; Hanley et al. 2006; Morrison and Bennett 2004; Van Bueren and Bennett 2004; Morrison and Bergland 2006.

Given the diversity of practices and under-appreciation of production theory, we conclude that the literature is badly in need of protocols for commodity definition, information treatments, and reporting—at least if the goal of the literature is to provide valid values interpretable by policymakers.

4. The Endpoint Decomposition-Recomposition Alternative

Using a systems perspective we have identified cognitive and interpretive issues associated with the use of commodities that are not ecological endpoints (direct inputs to home and firm production). First, non-endpoint commodities require subjects to estimate biophysical production relationships. Even if a subject can perfectly express the value of the resulting endpoint, the introduction of an intervening production process is likely to introduce error—error that is unlikely to be systematic across respondent populations. Second, non-endpoint commodities are often dual in nature. Unless this dual nature is explicitly decomposed by the respondent, they are likely to be confused by the direct versus indirect contributions of the commodity to welfare. Third, studies that present both a commodity that is an endpoint and a second commodity dependent on the first commodity as an input trigger potentially significant correlation issues that complicate the respondent's cognitive challenge and/or the analyst's interpretation of the elicited values.

One way around these problems is to reduce "systems confusion" on the part of respondents by eliminating the use of non-endpoint commodities and instead decompose the system into its endpoints. (We are aware that decomposition can create difficulties for studies, in part because respondents may not view nature as easily decomposable (Vatn and Bromley 1997).[29] Our hypothesis is that problems with decomposition may be due to respondents' lack of ecological systems knowledge. If provided with such knowledge (linkages between inputs, processes, and outputs) it is possible that decomposition may be more successful when joined to a depiction of ecological production relationships. We view this as a subject for empirical inquiry.

In theory, the system's decomposition into endpoints can then be followed by a recomposition of the endpoints so that complementarity and substitution effects across endpoints can be captured. (Note that when inputs, endpoints, and dual outputs are not clearly distinguished in valuation studies, it is difficult to assess complementarity and substitution effects and their role in elicited values).

To illustrate the properties of a decomposed, endpoint-focused commodity presentation, refer again to Figures 2-4 and the wetland example. The goal of the exercise remains the same: what is the value of the wetland? Recall from our discussion of production theory that the value of an unpriced input can be inferred if we have knowledge of the output's value and the production function that links the input and output.

In the wetland example, this means that we can separately measure willingness to pay for the three posited endpoints: open space, clean water, and crabs. With these WTP values, and with expert judgment from hydrologists, ecologists, etc. regarding the relevant production

[29] See Brouwer et al p. 11 ("People seem to enter a CV survey with a vague holistic value judgment rather than with explicit decomposed value judgments")

functions (wetlands to water quality; water quality to crabs) the value of the wetland can be derived.

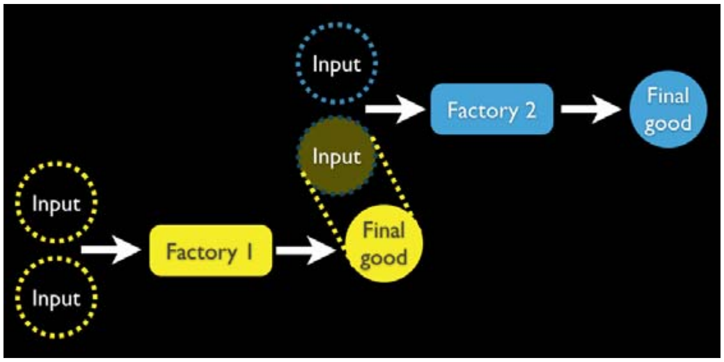
From a systems perspective there are several advantages to this approach (presenting only decomposed endpoints as commodities for valuation versus bundled commodities like wetlands). First, subjects are not required to understand the ecological system in order for the analyst to achieve a comprehensive valuation of the wetland bundle. It doesn't matter if a subject knows nothing about wetlands and their relationship to water quality, since they aren't being asked to value that relationship. Instead, they are being asked to directly value water quality. Second, the interpretation of valuations no longer hinges on the information assumptions associated with the subjects. Third, estimation of the production functions' role in generating value is left to those who can make the estimation most accurately: experts, instead of less informed subjects. Finally, endpoints can be recomposed into endpoint bundles in order to clearly detect substitution and complementarities effects across the endpoints (e.g., does a complementarity between open space and water quality affect elicited values).

Note that the problem with bundled commodities is not that they are bundled (recomposed). Rather, the problem is that most bundling involves the simultaneous bundling of *inputs and outputs*. Our theoretical suggestion is to isolate outputs from inputs and exclusively rely on outputs in the recomposed bundle—where demand interactions can be evaluated.

An illustrative metaphor

To illustrate the difference between decomposed endpoints as commodities and commodities used in the empirical literature, consider an industrial example (Figure 5). Imagine if we were to ask people to place a value on a factory (factory 1) that produces both a final consumer good and an intermediate good sold to another factory (factory 2). Now imagine we want to use stated preference techniques to derive the factory 1's economic value.

Figure 5. The Factory Production Analogy



Our “systems/endpoint/decomposition” approach to the problem is as follows: (1) identify factory 1’s final consumer good and ask respondents to value it; (2) identify factory 2’s final consumer good and ask respondents to value it; (3) use engineering and production analysis to determine factory 1’s role in production of factory 2’s output. With the two final good commodity valuations and knowledge of factory 2’s production process, derive factory 1’s value.

In contrast, consider a study that does not decompose the system in this way, but rather presents Factory 1 as the commodity to be valued by the respondent. Respondents will almost certainly return a positive WTP response for Factory 1, since all a positive valuation requires is an intuition that the factory produces something valuable. The problem is that an accurate valuation requires the respondent to (1) relate factory 1 to its outputs (what are they?); (2) estimate the value of those outputs; and (3) estimate factory 2’s production process and the productivity of factory 1’s output in that process. [Note the correspondence of this industrial example to the wetland-as-factory example above.]

Note the crucial difference between these two approaches. In the decomposition approach we advocate, respondents do not need to cognitively struggle with steps (1) and (3). Rather, the focus is exclusively on endpoints (“final consumer goods” in the example) with which they are familiar. This highlights the potential cognitive benefits of the approach—cognitive struggle tends to confuse, lead to scenario rejection, and open the door to presentation effects. It also highlights the greater accuracy of this approach. Who is more likely to accurately assess the stream of goods provided by the system and the underlying production relationships, experts or a random sample of households?

Moreover, the focus on final consumer good valuations allows demand interactions between them to be clearly identified. With "the factory" as the focus of valuation, these interactions must be cognitively dealt with by the individual respondent and will not necessarily be detectable by the analyst.

Finally, the metaphor highlights the interpretive advantages of our approach. With valuations focused on endpoints (final consumer goods), the users of the valuation result clearly understand the sources of value—the endpoints themselves. This acts as a relatively clear guide to decisions and management ("people value these outputs and value them this much"). If instead, the literature reports that the factory is worth $x, the research consumer is left to wonder…why is it worth that, and how should I manage factories based on that information?

If people are asked to place a value on a car, most will be able to do so. Most people (in the developed world anyway) have direct, tangible experience of automobiles and motorized transportation's role in their lives. We are accustomed to making choices about this kind of output: buy this car or that, or buy it this year or next. Now imagine asking people to place a value on the steel, glass, and labor used to make the car. This question is unanswerable with any precision since most people are not privy to the way cars are made. In other words, we have little experience of the production process and thus can only guess at production relationships and an input's role in generating valuable final outputs.

Valuation practitioners do not always have the luxury of defining ideal commodities. Sometimes, it is simply easier to measure inputs than endpoints. It may be much easier for an analyst to measure eagle habitat (and thus use it as the valuation commodity) than to measure the eagles themselves. Other times there is a desire to value ecological measures defined *for* the analyst by scientists or policymakers. If what is known to the policy process is that a preservation or management action will result in better lake acidity, river nutrient concentrations, or habitats, economists will be asked to elicit WTP values for those commodities. This leaves the economic analyst with a choice: present technical, input-like commodities to respondents or conduct a biophysical analysis themselves in order to translate the input-like commodity into an endpoint-like commodity.

Either way, if we want to know the value of a change in the input someone must know the production process that intervenes between the technical input and commodities relevant to home production. In the former case we rely on respondents to know it. In the latter, the analyst must know it.[30]

5. Ecological Production Theory and the Interpretation of Revealed Preferences

Revealed preference methods detect the value of nonmarket environmental goods by relating nonmarket goods to the value of private, market goods (housing, hourly wages, expenditures associated with recreation, etc.). Unfortunately, a given kind of market good will not usually reflect the full range of benefits associated with it. For example, the amenity value of open space to recreators who travel to visit it or commuters who enjoy the view on the way to work will not be capitalized into housing values. Nor will the value of the open space as an input to production of services (species, water quality) that are enjoyed further afield. Valuation practitioners often strive to communicate that revealed WTP is often an incomplete measure of a given resource's total value.[31] But policy audiences may miss this important nuance.

5.1 What Values are Captured in a Revealed WTP?

In contrast to stated preference studies where commodities are defined by the analyst, revealed preference studies rely on data—and thus commodities—that are empirically observable and practical to measure. Because of the practical measurement problem there is an understandable tendency in revealed preference studies to rely on what we called earlier "aggregated commodities"—like beaches (Bin et al. 2005), forests, cropland, and pasture (Irwin 2002), wetlands (Mahan et al. 2000), and open space (Smith et al. 2002).[32]

These aggregated commodities are bundles of endpoints and inputs. A beach, for example, is really a collection of endpoints: water quality, temperature, wave action, view, sand characteristics, and species populations. When beaches are found to be valuable via revealed preference the interpretation of that value hinges on deeper understanding of what specific endpoints are present and valued.

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[30] The inputs value can be "backed out" of the value of the final output, but only if the production function is known.

[31] As the authors note, "the hedonic property price method provides only a limited measure of total economic benefits. The estimates in this study measure only the amenity value of proximity to wetlands as perceived by nearby residential property owners." p. 600.

[32] Reviews of the revealed preference literature also note the tendency to rely on very general commodity definitions (McConnell and Walls 2005; Freeman 1995).

Ecological production theory can help practitioners communicate and differentiate the benefits likely to be captured by a revealed preference from those less likely to be captured. To illustrate, return to the wetland example depicted in Figure 3. Now imagine a hedonic analysis that finds a price premium for houses in proximity to the wetland. Are all of the wetlands benefits (those associated with open space, water quality improvements, and crab abundance) reflected in the hedonic premium? In truth, there is no way to know unless more detailed examination of households' utility functions is possible (say via a related stated preference survey). However, our ecological production approach generates a clear set of hypotheses to guide the interpretation.

First, we would decompose the wetland system into its components, as in Figure 3. Then, we would ask, which of these endpoints are likely to matter to consumers of the market good used in the revealed preference estimation? In the case of housing, the example system would identify the wetland's open space endpoint as being likely to matter to the utility of nearby homeowners. In effect, there is a clear linkage between the market commodity and consumption of open space. In contrast, the other two wetland endpoints are less likely to appear in the value of the market good. This is true for several reasons. First, wetlands' role in the production of clean water and crabs may not be known to homebuyers. Second, even if they are known, those benefits may not be enjoyed by the household. Improved water quality and crab abundance may occur far from the households in question (e.g., far downstream) in which case it is irrational to pay for those benefits (via a purchase price premium). Third, even if the production relationships are known *and* the resulting clean water and crabs locally enjoyed by the household, they are common property and thus the hedonic premium will likely underestimate the endpoints' true contribution to household utility. In this way, a systems approach can help clarify the interpretation of revealed values.

5.2 Systems Decomposition and Policy Relevance

Decomposition of environmental commodities is desirable for several reasons. First, environmental policy decisions often affect (positively or negatively) specific endpoints rather than more aggregate commodities. For example, policies may be geared toward water quality improvements 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."[33] The second reason for decomposition is the desire to transfer value estimates from one study site to others. Because aggregate commodities can vary widely in their composition (their specific endpoints) naive transfer of benefit estimates from one aggregate commodity to another is problematic. Benefit transfer requires us to control for similarities and differences in the aggregate commodity being transfer. In the language of this article, that means controlling for differences in endpoints that are bundled into the aggregate commodity.

The desire to decompose nature into more precise commodities that generate value is reflected in recent developments in the literature; for example, the move to linked stated and revealed studies. Linked stated and revealed preference studies (Cameron 1992; Eom and Larson 2006; Whitehead et al. 2000) use stated preferences to provide greater detail about the desirable environmental features that generate a revealed preference. In other words, Section 2's systems approach to state preference commodity definition, if deployed simultaneously with revealed value estimates, could provide a particularly detailed and interpretable set of valuations for environmental planners, regulators, and managers.

We also note the relevance of a systems approach to site choice modeling. Site choice models, by examining the choice of particular resource commodities like "parks" and "beaches" allow researchers to detect the contribution of more detailed commodity attributes to utility. The goal of site choice studies is similar to ours: decompose fairly general commodities into more specific commodities to more precisely understand what exactly in nature is beneficial to households. Our systems approach can help guide the search for, and measurement of, attributes most likely to be reflected in revealed choices.

In the revealed preference literature decomposed commodities are typically referred to as "qualities." These qualities correspond to endpoints as we have defined them. To quote Freeman (1995, 462):

> "When a number of different sites are being studied using a multi-site recreation demand model, there may be substantial variation in the qualities across sites. However, it may be difficult to disentangle the effects of differences in site qualities from the effects of differences in travel costs."

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

This issue is noted by reviewers of the hedonic preference literature as well. Problems associated with use of an overly general aggregate commodity like "open space" are cited (Cho et al. 2008;[34] Freeman 1995;[35] McConnell and Walls 2005[36]) as is the difficulty of measuring the specific qualities of open space that create value (Smith et al. 2002).[37]

When revealed preference studies measure specific endpoints they often matter—meaning, they have a statistically significant effect on valuations. Typically, only one or two such qualities are included in a study. (We are aware of no study that integrates a comprehensive depiction of qualities into a hedonic analysis.) But many examples of what we 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 et al 1999; Massey and Parsons 2002); specific species of fish found in a fishery (Freeman 1995); sand quality—grain size and amount of debris (Murray et al. 2001); "complex and natural" forest edges and conifers in rural areas, deciduous species with smoothly trimmed border in urban areas (Cho et al. 2008); elk habitat (Bastian et al. 2002); and a variety of water quality criteria including clarity, fecal contamination (McConnell and Tseng 2000), biotic integrity scores, water quality standards violations (EPA 2002), and nutrient concentrations (Bockstael et al. 1989, 1987).[38]

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 address this issue find that perceptions generally outperform objective measures (Adamowicz et al. 1997), but not always (Poor et al. 2001). We note that for practical reasons objective measures may be preferred because they are easier to collect. Measuring perceived qualities (which are akin to endpoints in our terminology) typically requires an additional survey instrument. Also, regulators and policy makers may prefer objective measures, particularly as an

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[34] "Despite the extensive use of the hedonic property method in valuing open space, few studies have valued the quality of the open space." 403.

[35] "It is surprising how few studies have focused on the role of qualitative attributes of beaches in explaining the demand for beach visits and the value of access to beaches." 398.

[36] "How open space is assumed to provide value and what variables are included in the econometric model could use more research… Surveys could be used to help inform hedonic models about which variables best capture what it is that people value and what is likely to be capitalized into house values." 68.

[37] "The task of developing an index to represent these (open space) amenities is more complex than most of the empirical literature has acknowledged." 127

[38] Greater disaggregation into a commodity's components does not always reveal differences in value, however. For example, Mahan et al (2000) found that housing prices are influenced by proximity to wetlands, but the type of wetland did not matter (open water, forested, scrub-shrub, emergent) to the valuations.

aid to benefit transfers, where objective measures are more generally available descriptors across sites.

For example, chemical oxygen demand, pH, nitrogen, and phosphorus levels are used as objective measures of water quality (Bockstael 1987, 1989; Egan et al. 2009). These measures are not endpoints, since they are not particularly meaningful to non-experts. But the use of household-unobservable, objective measures as proxies for endpoints (in this case threat of waterborne disease, species abundance, and observable water quality) hinges on the degree to which the objective measure is correlated with the endpoints households actually value.

6. Ecological Commodities in Natural Science and Regulatory Analysis

The biophysical sciences measure, track, and predict many ecological commodities (though they may go by different names, such as ecosystem structures, functions, qualities, features, conditions, etc). As a general statement the natural sciences focus on commodities that have theoretical significance, are practical to measure, and are considered direct measures or leading indicators of ecological condition and health. Measurement of these commodities is fundamental to ecological science and advances our understanding of underlying systems of biophysical production.

As a general rule, the units measured and reported in the natural sciences are most often what we term intermediate inputs, not 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 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, 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 and measured by ecological science is beyond the scope of this paper. However, it is instructive to compare endpoints as we define them to endpoints as defined by the U.S. EPA. In the 1990s the U.S. EPA created an Environmental Monitoring and Assessment Program (EMAP) designed to be a long-term program to assess the status and trends in ecological conditions at regional scales (Hunsaker and Carpenter 1990; Hunsaker 1993; Lear and Chapman 1994). More recently, the agency has developed Generic Ecological Assessment Endpoints (US EPA 2003). These initiatives are steps in the right direction. However, in both cases most of the endpoints identified differ from the kind we propose (in large part because they are designed to address legislative, policy, and regulatory mandates, not economic valuation).[39] The following are the "core" coastal and surface water EMAP indicators (U.S. EPA 2002b):

"Core" EMAP Coastal and Surface Water Indicators

o Dissolved oxygen o Salinity, temperature, depth o pH o Nutrients o Chlorophyll o Toxicity o Sediment grain size o Sediment metabolism o Total organic carbon o Sediment chemistry o Sediment toxicity	o Benthic, fish community structure & abundance o Fish pathologies o Fish tissue chemistry/toxics o Submerged vegetation o Fish, macroinvertebrate, & periphyton assemblage o Habitat structure o Riparian vegetation o Amphibians o Bacteria o Biomarkers o Riparian birds

The technical nature of most of these indicators presents a challenge to economic evaluation. Few of these "commodities" are in the realm of household experience and the connection between them and commodities people perceive as important to their own welfare is unclear.

Schiller et al. (2001) conducted an interesting analysis that presented EMAP indicators to focus groups of non-scientists. The focus groups were asked to evaluate the indicators, 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." While the study is not an economic analysis *per se*, it

[39] We emphasize that these endpoints were developed to satisfy the legal and technical needs of the agency, rather than to foster economic assessment: "criteria used for selecting the GEAEs were that they must be useful in the EPA's decisionmaking process, practical, and well defined. Utility was based on policy support including citation in statutes, treaties, regulations, or agency guidance and on precedents."

highlights the need to bridge the gap between natural science and individual preferences via greater attention to the translation of ecological outcomes into outcomes that are meaningful to a non-technical audience.

Another conclusion of their study pertinent to ours is that respondents tended to prefer general commodity descriptions to specific ones. An exception was when a specific species is endangered or species that are recreationally focal (e.g., brown trout). This finding is consistent with what we would expect from our discussion in Section 2. Recreationally focal species are understandably perceived to be directly important to household welfare, as are endangered species which are tangible and relevant to households that care about extinction. In contrast, statements about species in general are not as useful to respondents because they are statements about the underlying system, rather than about inputs to household production. It’s not that such measures aren’t important, but rather that respondents don’t know how to interpret the information.

Finally, we note that the growing adoption of an “ecosystem services perspective” in ecology is promoting the development of endpoints that are more useful to economic assessment. For example, the literature on pollination services yields insights into the delivery of pollen to commercially valuable crops (Ricketts 2004; Kremen and Ostfeld 2005; Balvanera et al. 2005; Priess et al. 2007).

Another window onto commodity definition is through economic analyses of proposed environmental regulations (called Regulatory Impact Analyses or RIAs) that address ecological commodities. Below is a list of such measures covering RIAs finalized between 1998 and 2008 (see Abt 2008, Table 16).

Biophysical Measures Valued in EPA Regulatory Analyses

o Number of species saved o Change in estimated commercial and recreational fish landings/catch o Reduced fish mortality o Change in fish impingement and entrainment o Change in shellfish populations o Reduced contaminant levels in fish tissue o Acres of mine lands improved	o Changes in a water quality index o Change in sediment loads, turbidity, total suspended solids o Change in number of water bodies or reaches exceeding ambient WQ standards o Change in tons of sediment dredged o Change in number of streams receiving toxic incursions o Fishing habitats improved o Improved fisheries

Many of these commodity types (and the issues they raise) have already been discussed above (for example, the use of quality indices like the water quality ladder, catch rates, and individual mortality and toxicity statistics.)[40] Indeed, they cover the full range of endpoints we discuss in the theory section—covering mortalities at the unit to and species level, changes in habitat, changes in the quality of habitat, and changes even more remote from the object of value, such as changes in tons of sediment removed.

In some of these cases, the commodity definition is of concern because it is vague. For example, acres of mine lands or fishing habitat "improved" begs the question: improved *for what end*? Number of streams receiving toxic incursions is important, but the definition of an incursion and how that relates to health or ecological risks is unclear.

[40] See section 2.

In other cases, the commodities are chosen because the value is derived from a specific user group, and not necessarily households. For example, turbidity, total suspended solids, and sediment loads may be difficult for households to value. However, these commodities are being used to derive values from avoided costs of treatment. Thus, "the public" is not the source of the valuations here. Rather, the source is public utilities and treatment operators. This community is generally able to translate technical water quality criteria into treatment costs, because of their knowledge of treatment technology.[41]

7. Conclusions and Implications for Future Research

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

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 reference to a larger system. By linking these endpoints to a production system, subjects, analysts, and readers can—in theory—more clearly understand production linkages that are real, qualitatively intuited, but also a source of confusion, error, and misinterpretation. Production theory allows for the dual, bundled nature of ecological commodities to be clarified and the minimization of problems associated with double-counting. Our perspective clearly favors the use of choice experiments over CV because of the greater control the analyst has in bundling or unbundling commodities.

To illustrate these ideas we compared a sample of stated preference commodities to the commodities implied by a production theory approach. Here, we found reasons to suspect the accuracy of many stated WTP estimates. The problem, as we see it, is under-appreciation of the

[41] While not technically "households" utilities are the relevant economic decisionmakers in this example. They are in the best position given their knowledge of the commodity, to give it an economic value. As noted earlier, farmers, via their knowledge of agricultural production, are in a good position to value biophysical inputs like water availability and quality, and pollination. Not all farmers are "households" either.

distinction between ecological *inputs* versus endpoints and the cognitive challenges input-like commodities create for respondents.

Our review of the literature clearly suggests that studies need better report how they choose and then describe the commodity both in pre-testing and in the survey itself. Approximately half (32) the studies we reviewed did not provide details on pre-testing protocols and the ways in which environmental commodities or systems were described. In the rest, we can find some information on the role of discussions with experts, including government officials, biologists, scientists, environmental consultants, and resource managers. But the effect of these discussions on commodity definitions is not reported. In several cases, laypersons and resource users were said to have played a critical role in the development of the survey instruments. But only 45 of the studies even provided the WTP question in the published article. In general, it was very difficult to understand from many articles the information treatments that people were given vis-à-vis the production system and commodity approach we advocate.

In general, we found little evidence of commodity definition driven by clear economic or biophysical principles. We hope that the paper will contribute to a more concerted debate about what those principles should be. Currently, the literature exhibits little or no uniformity in terms of commodity definition. And the commodities that are used are often far from the prescriptions offered by our approach. Given the diversity of practices and under-appreciation of production theory, we conclude that the literature is badly in need of protocols for commodity definition, information treatments, and reporting - at least if the goal of the literature is to provide valid values interpretable by policymakers. Ultimately, we would like to see commodity definition protocols much like the NOAA protocols already in place for design and analysis of data from CV studies. Protocols would facilitate the comparability of studies and clearer interpretation of WTP results by policy audiences. Moreover, protocol development would facilitate a needed (and in our view neglected) conversation about commodity definitions and their influence on WTP.

Before such protocols can be defined, several types of empirical research are needed in order to verify or reject the hypotheses generated by our approach.

The central empirical question is: does presentation of endpoint-type commodities to respondents (versus ecological inputs, processes or dual commodities) reduce cognitive errors, confusion, and scenario rejection associated with fuzzy intuitions about ecological production. What is the effect on subjects of presenting endpoints attached to illustrated systems of ecological production versus presenting them without an associated system? Does our approach to decomposition and recomposition of commodities overcome subject resistance to disaggregation of bundled commodities? Can subjects be distinguished based on *ex ante* ecological process intuitions and if so what is the effect of these intuitions on WTP? Specifically, we propose the following empirical strategy:

First, conduct research on ecological mental models to explore the degree and type of process intuitions people bring to their perceptions of nature. These mental models could then be compared to expert mental models. For a given resource like a wetland, how do the mental models compare? Can they be reconciled? How complete are respondents' mental models relative to the experts? How do subjects decompose the wetland into its constituent parts, what level of aggregation do they use to describe the commodity? How homogeneous are these mental models across subjects?

Second, conduct focus groups. Based on the results of the mental models analysis, as well as the expert model, use focus groups to test information treatment materials to be used in a subsequent survey. These groups would explore the role of ecological production-based treatments that provide information t on the system in question, distinguishing between endpoints, inputs and processes, and that describe dual and compound commodities. What is the reaction of focus groups to this kind of information treatment? What is the most effective degree and type of production system information to provide (do the kind of diagrams used in this paper help respondents with their cognitive task? Can they help isolate commodity-specific demand?

Third, conduct pilot studies sufficient for hypothesis and robustness testing. Based on the focus group results a series of surveys could be developed for hypothesis and robustness testing. Scope tests and other statistical tests can be used to examine how different information treatments and commodity definitions perform. Protocols to measure performance would need to be devised. Perhaps better performance in scope tests and tighter variances of WTP would be evidence that a particular information treatment of commodity definition is outperforming alternative definitions.

Finally, we note that a systems approach to commodity definition will support the development of benefit transfer functions. 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, and 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).

In order to judge the relevance of a particular study to a particular new site, it is necessary to know how comparable those sites are. A key to that comparability 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.

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