Valuation of Forest Amenities: A Macro Approach

by
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Abstract

A method of estimating forest amenity value based on macroeconomic growth theory is presented. It relies on the assumption that more valuable forest amenities are provided by a forest with a more natural stand structure. We construct a forest naturalness index from stand data that provides a relative measure of the forest amenity provided regionally. This naturalness index is meant to assess the change in forest amenities over time. It is a measure of diversity within the allowable specimens (species/diameter/height) of the natural forest type and observed successional stage. We aggregate the fraction of maximum diversity of the natural forest type for the target successional profiles of the natural forest types of the survey unit to calculate the index for the region. The paper shows a specific form for the path over which aggregate consumption, including forest market goods, and forest amenities, as measured by our naturalness index, evolve. This macroeconomic growth model assumes a trade-off between consumption growth and forest amenities. The present value of future consumption foregone by a marginal increase in the naturalness index is the shadow price of the forest amenity represented by the index increase. The value of any proposed forest policy change is the value of the index change that the new forest policy causes.

Environmental Change and Economic Growth

Optimal management of the many values supported by a forest resource requires an assessment of a price of each of those values. Whether we are trading off multiple uses of public forests or establishing the optimal level of funding to facilitate some value of the forest, we need prices to analyze the policy choices. This need for prices is also true beyond public lands to the extent that we do establish policies that influence the total forest resources of a region including those on privately held lands.

Whether a rational optimization calculation of the best forest policy is formally made or not, we do observe changes in the state of forests which result from policy actions or lack thereof. The overarching concept behind this research is that the state of the forest we observe implies prices for forest values even if they have not been explicitly identified.

Prices for many goods provided by the forest are as conceptually straightforward as observing market transactions. Timber prices, grazing rights and many other non-timber commodities are bought and sold so the prices observed in those transactions are the prices that we use in benefit cost analysis. But, many values provided by the forest are not traded in markets. Forests provide environmental services, which are public goods, so due to the free riding problem, market information provides a distorted price. The forest also provides amenities, such as scenic beauty and the value of simply existing that are difficult if not impossible to reduce to a market commodity.

Methods have been developed to estimate the value of these non-market goods. With the travel cost method and hedonic pricing method we observe choices of individuals and infer the price individuals are willing to pay for access to amenities. With the contingent valuation method, we experimentally construct markets by polling individuals with questions that either directly or indirectly relate to the value of amenities.

One aspect common to each of these valuation methods is that we imply the price by observing the behavior of individuals. Our approach in this project is instead to observe aggregate behavior in a region and infer an aggregate value for forest amenities. In this macro approach there is a trade off between consumption growth and the state of the forest. The present value of consumption goods a region gives up to prevent a marginal degradation in forest naturalness is the price the region effectively puts on that change in forest state.

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We model this trade-off using an approach based on economic growth theory. This approach has been proposed by Stokey (1998) to explain the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis simply stated is the proposition that for a wide class of environmental amenities, those amenities will at first worsen as per capita national income increases from a low level and then after a peak, the environmental amenity will improve with further increases in income.

Forest landcover has been subject to limited study in the EKC empirical framework. Shafik and Bandyopadhyay (1992) found that both net change in forest cover and annual deforestation did not significantly relate to income in an international set of 149 countries between 1961 and 1986. Panayotou (1993) using strictly cross-sectional international data reports a turning point in deforestation at a GDP per capita of $1275 in 1985 prices. Cropper and Griffiths (1994) create pooled time series cross-section data for three separate regions of the world. Per capita national income is a significant factor in both Africa and Latin America, but not in Asia. Stern, Common, and Barbier (1996) use the published EKC deforestation data to predict that forest loss stabilizes overall by 2025, but tropical deforestation continues at a constant rate. Finally, Patel, Thomas, and Jaeger (1995) find that the pattern of fuelwood demand in Kenya will eventually cause the decreasing tree cover to increase. Koop and Tole (1999) conclude that the same simple forest cover EKC relationship does not hold without accounting for other international differences. The applicability of these papers to the issue of forest amenities is questionable, since forest cover itself may not be a sufficient measure of EKC type environmental amenities provided by forestland.

Measuring Forest Naturalness

We will calculate a measure of forest naturalness from FIA survey data using a clearly defined procedure that assesses an overall grade for the forests in a region. In theory, the proposed model can be extended to a multiple dimension measure of the capacity of forests to provide amenities. But, we limit the scope of our current work in this project to a one-dimension naturalness score.

Although a consensus has not yet developed on a complete definition of naturalness much less on the relative weightings of different natural aspects of the forest we wish to express as a single score, such a measure is useful for our purposes. If all of the natural amenities provided by the forest increase monotonically with our naturalness index, then a linear approximation is appropriate to compare relatively small differences in naturalness score. In this case, the marginal tradeoffs between the different amenities of interest are relatively constant, so the naturalness measure will faithfully reflect forest amenities averaged together by the naturalness index calculation procedure. We expect that a significant part of the attributes of a forest that make it natural correlate with our measure even though we do not measure many of them directly.

To the extent that our measure does not correlate at all with some forest attributes, we have simply defined those attributes as not natural in our sense of naturalness. The objective in defining a naturalness index is not to construct a perfect measure of naturalness, but rather to define one that captures enough natural qualities to proxy for a useful part of the amenities provided by forests.

If some single easily defined stand state were the natural condition, then calculation of a score based on the deviation from that stand state would be simple. The most difficult aspect of assessing naturalness is that many states are perfectly consistent with a natural forest in the original-naturalness sense of natural described by Peterken (1996). Great diversity is characteristic of the natural forest including large areas dominated by a few early successional species in some forest types. The natural forest includes recently disturbed sites and areas of forest succeeding that disturbance ranging to a mature forest. This variety in the forest is observed at the stand level and at the landscape level. In our approach we define adherence to a natural disturbance regime and diversity of natural tree types at both the stand and landscape level to be the most natural forest.

A rich variety of approaches are taken by past efforts to define naturalness or related qualities of forests. The “health” of a forested landscape is defined by the condition of a multitude of natural attributes of the forest. The Santiago Declaration (Montreal Process, 1995) identifies seven criteria for evaluating the state of conservation and sustainable management of temperate and boreal forests. Multiple indicators are identified for each of the Santiago criteria. For example, criterion 1 is the conservation of biological diversity, which consists of ecosystem diversity, species diversity and genetic diversity. Ecosystem diversity is indicated by a) the area of each forest type, b) the area of forests in age classes and successional stages, c) the area of critical forest types, d) the area of critical forest age classes and successional stages, and e) the fragmentation of forest types. Similarly, The State of the Nation's Ecosystems (H. John Heinz III Center, 1999) provides a multidimensional assessment of forests.

Some efforts to define forest naturalness use somewhat subjectively evaluated scales. Peterken (1996) defines a "scale of naturalness" by describing eight categories from a treeless pasture to virgin forest with increasing degree of wilderness. Schnitzler and Borlea (1998) define a "scale of increasing naturalness" based mostly on stand characteristics plus some landscape structure information. This scale of naturalness is along six dimensions: four at the landscape level and two at the stand level. Numerical criteria are described for placing a forest in a ranked naturalness category for each dimension.

We have designed our naturalness index to measure these criteria as directly as we can while restricting ourselves to data collected by FIA surveys. The first component of our naturalness index is stand level diversity of tree types. By tree type, we mean not only species, but also diameter, height, cavity tree status, and crown class. For each plot we assess the diversity weighted by basal area using a Shannon index normalized to a 0 to 1 scale. The tree types must be allowed in the potential natural type and successional stage of the forest to be counted. To the extent that a non-native tree type (e.g. buckthorn is a noted invasive tree species in Southern Wisconsin.) displaces native trees, the naturalness is lowered. This is true for the diversity measure defined below because the partial derivative with respect to the basal area of each allowed tree type is negative when we hold everything else constant except replacing the tree type with an unnatural type.

The list of tree types allowed in the forest is a key element in our definition of natural. These tree types are defined specific to both the potential natural forest (PNF) type and the succesional stage we identify for a survey plot.

We identify the PNF of a plot from the coordinates and other characteristics of the plot. From the longitude and latitude of the plot, we identify the Omernik Ecoregion potential forest type (USGS, 1990). We further differentiate forest type based upon site physiography, slope and aspect. For the identified PNF, we identify the successional stage from the stand data. For example a site with few trees large enough to be reported serves as a recently disturbed site. A stand dominated by southern pine in some PNFs might serve as an early successional stage and dominance by hardwoods might constitute late successional or a mature forest stage.

We calculate of average plot diversity, S^P_{ij}, for a PNF type *i* in the survey unit that is in successional stage *j*:

$$S_{ij}^{P} = \sum_{k} \frac{A_{ijk}}{A_{ij}} \left[\frac{-1}{\ln(n_{ij})} \sum_{l} \left(X_{ijkl} \ln(X_{ijkl}) \right) \right].$$

i – potential natural forest type of the plot
j – successional stage (regenerating/pioneer/mature)
k – FIA survey plot
l – tree type (species/size/canopy status)
X_{ijkl} – fraction of basal area on sample plot *k* that is classified as type *l* tree
n_{ij} – number of tree types in forest type/successional stage

The first aspect of this calculation to consider is the diversity index we calculate from basal area fraction of allowed tree type *l*, X_{ijkl}, in the summation on the left of the expression. The denominator for the basal area fraction is the total basal area in the stand including unnatural specimens. Secondly, notice the scaling. We use the coefficient n_{ij}, the total number of tree types we identified as natural in *ij* as discussed above, to scale the diversity index to a [0,1] value. The third aspect of this calculation is that we are averaging the diversity weighted by acreage. The forest acreage the survey plot represents, A_{ijk}, (the expansion factor for plot k, which we find to be an *ij* stand) is summed for all of the ij plots in a survey unit to get the total area of forest type *ij* in the survey unit, A_{ij}.

Patches concentrated with one tree species are common in many otherwise very diverse natural forests. Thus, the most natural average diversity is lower than a possible highly uniform mix of many different tree types. We expect at the survey unit level that the influence of such an unnaturally diverse forest will not significantly distort the data. While some such forests might be constructed, it is hard to imagine that enough forest has been managed in such a way that the average naturalness over a survey unit would not be higher for a higher diversity number.

The survey unit wide or landscape level diversity of tree types is also richer for a more natural forest. Thus, we account for the landscape scale diversity in our naturalness measure with:

$$S_{ij}^{R} = \frac{-1}{\ln(n_{ij})}\sum_{k}\left[\sum_{l}\left(\frac{A_{ijkl}}{A_{ij}}X_{ijkl}\right)\ln\sum_{l}\left(\frac{A_{ijkl}}{A_{ij}}X_{ijkl}\right)\right].$$

The summations within the brackets calculate an acreage weighted average basal area fraction for tree types survey unit wide. This is the diversity of allowed tree types in all PNF type i in successional stage j survey unit wide.

We bring both of these measures together using an acreage-weighted average for all PNF/successional stage types in the survey unit.

$$N = \frac{1}{A}\sum_{i}\left\{A_{i}\sum_{j}\left\{\frac{A_{ij}}{A_{i}}Max\left[1,\frac{A_{ij}}{f_{ij}A_{i}}\right]S_{ij}^{P}S_{ij}^{R}\right\}\right\}.$$

The inner summation averages the product of the two diversity values over the successional stages in a PNF. A more natural forest will adhere to a natural disturbance regime. The coefficient f_{ij} reflects this natural disturbance pattern. This parameter is the average fraction of the forest that will be in successional stage j for forest type i. We aren't able to directly discern spatial characteristics of these stands in a successional stage, but the profile of the total area in the region is an important part of the disturbance regime, which we do assess. For example if it is estimated that forest openings form every 200 years on average, then f_{ij} is 0.5%. The diversity averaged among disturbance regimes allows the diversity of only the target fraction of area in a disturbance regime to contribute to the naturalness score. If one successional stage is over-represented then the other stages will be under-represented and the total weighting of diversity scores will be less than if the disturbance pattern conforms to the natural profile. The average of these disturbance regimes corrected average PNF diversity indices are next averaged weighted by the area of the PNF in the survey unit.

To summarize, we average the diversity of allowed tree types in each potential native forest type in a region. This PNF type is defined by the Omernik Ecoregion in which the coordinates of a survey site fall along with the physiography, aspect, and slope identified for the site and the successional stage of the site implied by the stand state. In addition to identifying allowable native tree types for a PNF, a target successional stage rotation is identified. Deviation from the target succesional stage profile lowers the naturalness score. Size, crown class, and tree status in addition to tree species define the PNF allowable types.

This naturalness measure is a proxy for all forest amenity provision level. Thus, our amenities are defined as those that increase with this naturalness measure. That these amenities increase monotonically with the naturalness measure is more important than the exact shape of that change since that change will be approximately linear for small changes in the measure.

Modeling Economic Growth

The economic growth model is adapted from the exogenous technological change model for pollution stocks described by Stokey (1998). We rely on cultural and ecological similarities in our southern region of interest to greatly simplify the model and allow empirical calculation of the model parameter vector with greater potential statistical confidence. We will use the naturalness measure to proxy for forest amenity provision. We propose to use county level personal income data from the Bureau of Economic Analysis (Department of Commerce, 2000) to proxy for consumption. The average - growth rate of personal income is approximately the average consumption growth rate under the permanent income hypothesis. And, the personal income level taken from the constant growth rate curve is approximately a constant multiple of the consumption level under the same hypothesis. Thus, in a survey unit we need an FIA survey and personal income data encompassing the survey date for an observation. We will assemble a panel of such data from the multiple survey dates we have in each of the 72 survey units of the south.

The same vector of model parameters is valid for each datum, but, in our econometric model this vector is drawn with random error. Thus, an unbiased estimator for the model parameter vector is:

$$\underset{\{A,B,d,g,\beta,\gamma,\eta,\sigma\}}{Min} \sum_{\forall i} \left\{ \left[z_i^{1-\beta} c_i^{-\sigma} - d(c_i g_{ci})^{-\sigma} z_{i+1}^{1-\beta} (1-\eta) - dB\beta(-\ln(N_{i+1}))^{\gamma-1} \right]^2 \right\},$$

$$where:$$

$$z_i = \left\{ \frac{\beta}{Ag^t(\beta-1)} \left[g_{ci}^{\sigma} d - 1 \right] \right\},$$

$$z_{i+1} = {z_i}/{g}.$$

Where g_{ci} is the average per capita personal income growth rate, c_i is the per capita personal income from the smoothed curve at the time of the survey, and N_{i+1} is the naturalness calculated from the FIA survey data. The variables z_i and z_{i+1} are measures of technology, which are endogenous to the model. The time in years from the base year 1980 is t. The eight other symbols are the parameters of the model. An empirical distribution will be bootstrapped by repeatedly calculating this estimator from sets drawn randomly with replacement from the database (Efron, 1979).

Value of Forests

After we have calculated a distribution for the vector of model parameters, we have what we need to calculate the value of all of the amenities associated with the forest stand state. The total value of the forest amenities at any given time does not really make sense in this model, but the value of a change in forest state does. The value of a change in forest state is not only the value today, but also how it affects that change in the future.

$$P_{Nt} = \frac{n_t B c_t^{\sigma}}{N_t} \sum_{i=0}^{\infty} (-\ln(N_{t+i}))^{\gamma-1} [d(1-\eta)]^i.$$

The price, P_{Nt}, is the value of a marginal change in the forest naturalness index, N_t in \$1998. We multiply by the population, n_t, to convert from a per capita economy to the whole regional economy. We divided by the shadow value of consumption ($\lambda_t = c_t^{-\sigma}$) so that price is expressed in terms of consumption units (\$1998) instead of utils. We multiply by the slope of the relationship that defines the naturalness index ($dx_t/dN_t = -1/N_t$) so that we have the price of the change of index rather than the cost of another unit of forest degradation. Each year the marginal cost of degradation is $B(-\ln(N_t))^{\gamma-1}$, but this is affected by the future only after correcting for natural regeneration $(1-\eta)^i$ and this marginal affect of change today on the future is discounted by the factor d^i to a present value.

As an example, we can apply this price to the analysis of benefits and costs during the Land Resources Plan (LRMP) process. If in the management plan we have a planned forest state for the whole region into the future, we can calculate a price for a small change in forest state directly from the equation above. If we plan for the forest state to converge to some constant state in the future, then we use standard mathematics of infinite series to calculate the present value of the future discounted marginal utilities. With any number of different management alternatives with different forest states, we can calculate the corresponding naturalness index values for each alternative. Multiplying the amenity price by the difference in index between any alternative and the alternative with the lowest index gives us the dollar value of the benefit of the additional forest amenity.

Alternatively, we can calculate this price without future forest state data if we recognize that part of P_{Nt} is the shadow price, μ_t, of forest degradation:

$$P_{Nt} = \frac{n_t B c_t^{\sigma}}{N_t} \left[(-\ln(N_t))^{\gamma-1} - \mu_t \right]$$

For an economy past the EKC hump, we need only the rate of consumption growth and the level of consumption to calculate μ_t using the model parameters we estimated.

$$\mu_t = \frac{-1}{\beta} c_t^{-\sigma} \left\{ \frac{\beta}{Ag^t(\beta-1)} \left[\left(\frac{c_t}{c_{t-1}} \right)^{\sigma} d - 1 \right] \right\}^{1-\beta}.$$

Conclusions

This method is a basis for forecasting trends in forest amenity provision, and a way to evaluate the value of a marginal increase in that amenity. Long term forecasts of the level of demand for a forest amenity will be useful for designing forest management to achieve the desired forest state in a timely manner.

As an example, suppose the predicted increase in the required level of forest amenity over the next forty years can be achieved for a region by converting some even-aged plantations to a more natural forest composition. With the advance forecast, the forest type conversion can be accomplished smoothly as the plantations mature and with some confidence that the balance of competing interests will be satisfied with the amount of natural-appearing forest available at that future date.

The proposed model will provide a shadow price for the forest amenity for any date given the projection of the personal income at that date. This shadow price is the value of an increase in the provision of the amenity. The value of the forest amenity will be informative in cost benefit studies.

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