FOREST BIODIVERSITY AND TIMBER EXTRACTION: AN ANALYSIS OF THE INTERACTION OF MARKET AND NON-MARKET MECHANISMS*

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Abstract

 Forest ecosystems provide a range of products and services for human use, primarily due to the biodiversity inherent in them. From the ecological viewpoint, this diversity is of different kinds and has the potential to cater to human well-being in multifarious ways. However, the mix of services that is available to any economy from forests depends, in addition to their biological characteristics, on the nature of the economic regime within which they are exploited. Some commodities such as timber are extracted in a regime driven, in the main, by market forces. Others such as non-timber forest products may be extracted under a variety of arrangements, the range varying from open access to common property regimes. Services such as those of water cycle augmentation and micro-climate regulation are typically available to communities as free goods.

 It is hypothesized that this difference in institutional regimes has implications for the mix of products and services that are extracted in different ways
- through its effect on the extraction efforts for the marketed product.
- because of policies, such as plantation, which are intended to increase the supply of the marketed product, typically, timber
- through a change in biodiversity of the forest stock which in turn results in a decreased availability of the non-marketed products

The present paper studies conditions under which timber has been extracted from forests of the north Indian state of Uttar Pradesh during the period 1975 to 2000 to examine this proposition. It is postulated that extraction of timber at any point of time depends on the stock, the effort involved in extraction (as represented by the per unit cost of extraction) , the biodiversity index (defined as a product biodiversity index) and a variable depicting ecological characteristics of the forests. Using a modified Gordon-Schaefer production function, and the assumption that forests are managed for "sustainable timber extraction" the reduced form equations are derived and estimated using data from Uttar Pradesh forests for the period 1975 to 2000.

The results suggest that , in the absence of variables representing the plantation area and bio-diversity corrected stocks, the explanatory power of the model is low, even though extraction is seen to be significantly impacted by effort. If, however, the ratio of plantation area and biodiversity adjusted extraction are introduced as explanatory variables, interesting results with respect to the trend of extraction over time are obtained

As stocks of woody biomass increase, extraction increases. A decrease in bio-diversity of the stock may be accompanied, under a certain set of circumstances, with a rising trend in extraction, and at a rising rate as explained above:. However, an increased biodiversity, may imply a decreasing trend in the extraction in the future provided that present extraction Y does not rise at a rate faster than the rate of increase in the biodiversity. These two results seen together are, we believe, significant. They point to the fact that policies aimed at increasing plantation   increase short run timber extractionII

Further, if biodiversity increases, the impact on future extraction of timber depends on relative rates of change in biodiversity and extraction per unit effort. It is clear that trade-offs between timber extraction and existence of bio-diverse forests providing a variety of goods and services.

I. **Introduction**

Forest ecosystems provide a range of products and services for human use, primarily due to the biodiversity inherent in them. From the ecological viewpoint, this diversity is of different types and levels and has the potential to contribute to human well-being in multifarious ways. However, the mix of services that is available to any economy from forests depends both on their biological characteristics and on the nature of the economic regime within which they are exploited. Further, the economic arrangements that govern forest extraction are of different kinds. Some commodities such as timber are extracted in a regime driven, in the main, by market forces. Others such as non-timber forest products may be extracted under a variety of arrangements, the range varying from open access to common property regimes. Services such as those of water cycle augmentation, prevention of soil erosion (through the watershed functions) and micro-climate regulation are typically available to communities as free goods.

It is hypothesized that this difference in institutional regimes has implications for the mix of products and services that are extracted in different ways

- through its effect on the extraction effort for the marketed product
- due to policies such as plantation which are intended to increase the supply of the marketed product, typically, timber.
- through a change in biodiversity of the forest stock , which in turn results in a decreased availability of the non-marketed products

The present paper studies conditions under which timber has been extracted from forests of the north Indian state of Uttar Pradesh during the period 1975 to 2000 to examine this

proposition. It is postulated that extraction of timber at any point of time depends on the stock, the effort involved in extraction (as represented by the per unit cost of extraction) , the biodiversity index (defined as a product biodiversity index) and a variable depicting ecological characteristics of the forests. Using a modified Gordon-Schaefer production function, and the assumption that forests are managed for "sustainable timber extraction" the reduced form equations are derived and estimated using data from Uttar Pradesh forests for the period 1975 to 2000.

The paper is organized as follows. Section II reviews different approaches to the measurement of biodiversity in order to place the proposed "bio-economic diversity index" in context. Section III presents the theoretical and econometric model underlying the analysis. Section IV looks at forests and forest policy in the Indian state of Uttar Pradesh. Section V estimates the model and the last section concludes the paper with comments and observations

II.1 Characterisation and Measurement of Forest biodiversity

Biological diversity is defined as the variety and the variability of different life forms. The life forms could range from the molecular level (DNA) to the biome level. While, at the conceptual level, a number of well-defined and widely accepted definitions of bio-diversity exist, its characterization and measurement still remain an issue of concern. Characterisation depends on three disciplines[1]:

- Taxonomy which provides the reference system and depicts the pattern of diversity for all organisms
- Genetics which provides knowledge of the gene variations within and between species
- Ecology which provides knowledge of the varied ecological systems in which taxonomic and genetic diversity is located.

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[1] See Bisby (1995) for an overview of different approaches to biodiversity characterization.

Often, analogous to the approach which ecology adopts, biological diversity is characterized and measured with respect to particular eco-systems such as wetland ecosystems, grassland ecosystems, forest eco-systems etc. Our specific interest in this paper is in this aspect of bio-diversity with reference to forest eco-systems, which constitute a major share of global biological resources and their biodiversity. According to one estimate, half of the vertebrates, 60% of the known plant species, and 90% of the total world species are found in tropical forests alone (Flint, 1992)..

It is not possible to set-up an all–embracing scheme of biodiversity measurement which represents all components of biodiversity for different forest ecosystems. Different aspects of biodiversity are captured by different indices. Measurement of forest biodiversity becomes all-important not only due to the existence of species richness in forests but also due to its fragility and the subsequent ecological and economic implications.

To begin with, biodiversity from an eco-system perspective can be viewed as species diversity, within areas or between areas. Ecologists have for long distinguished between '*alpha*' and '*beta*' diversity. Further,they have long known that a relationship exists between the number of species and the size of an area. A modified form of this is sometimes referred to as the "*island biogeography theory* ". An assumed species area relationship is used to estimate the biodiversity in forests as shown by the following equation:

$$S = cA^Z$$

Where, S is the number of species, A is the area and c is a parameter that depends on the group of species,[2] its population density and the biogeographic region. 'Z' determines the shape of the species area curve and has values between 0.15 and 0.8 for most regions of the world. Z factors have inverse relationship with the area under consideration i.e. as the area under consideration increases the Z factors become smaller. Islands have higher Z factors than continental areas. (Mcguiness1984)

However, species richness and species diversity as measures of biodiversity treat all species equally. We know however, that different species may make different

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[2] See McArthur and Wilson (1967)

contributions both from a biological perspective and from a utilitarian economic perspective. Such perceptions of difference lead to their own measures of biodiversity.

From a biological standpoint, one can distinguish between *taxic and functional diversity,* both of which refer to relations between species. In a forest eco-system, functional phenomenon can be divided into an array of processes such as photosynthesis, transpiration or the flow of energy and matter through a forest ecosystem, which are mainly driven by the abiotic environment (e.g. sunlight, temperature). In this context silvicultural interventions can be considered as a controlled disturbance to favour certain parts of the population (e.g. individuals, tree species, etc.) or processes (e.g. tree growth) within a forest ecosystem. Functional biodiversity refers in particular to ecological functionality which may have two kinds of consequences

- for a species itself in isolation, referred to as *autecological diversity*
- for the living together of a set of species referred to as *synecological diversity*

In a forest eco-system context, both of the above are relevant since we are concerned with " plants, animals, micro-organisms and physical environment at any given place and the complex relationships linking them into a functional eco-system"[3].

II.2 Functionality and Bio-diversity in relation to human use: Bio-Economic Indices

Humans, governed by their anthropogenic norms and behaviour, define functionality with respect to human use. A variety of bio-diversity measures have been developed with such a focus, albeit from different viewpoints and at different spatial scales. The focus of conventional forest management has, for instance, been on timber production and is defined almost exclusively at the stand level. Regional planners consider some broader issues of the forest sector. In contrast, the measurement of biodiversity from the sustainability perspective requires the inclusion of all spatial scales.

Bioeonomic indices of forest diversity are also aimed at capturing the diversity of forest eco-systems in terms of their use by humans. The two-way division of forest products

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[3] For the eco-system concept, see Tansley (1935). See Appendix 1 for deails on measurement of biodiversity.

into non-timber and timber produce constitutes a distinction between diversity based use and single product based use of a product with market- value. Non timber forest products obtained from the forest constitute a range including fuel-wood, leaves with economic value (tendu and sal for instance), roots, canes, herbs, seedlings, honey, gums and resin. Timber may also come from different species but is typically treated as a single product, . It is postulated therefore that, an index capturing the number of products being extracted comprises a good proxy to measurement of biodiversity- in- use. Each product is given a weight which is determined by the value that society places on it.The weighted index of biodiversity is therefore defined as the index in which values are used as weights for the different Y_i. Note however that timber values are measured by market prices and non-timber product values are approximated in a variety of ways reflecting the economic regimes under which they are extracted. Non-timber product values capture the imperfect nature of the markets in which they are evaluated. They may reflect opportunity costs of labour or the relatively lower access of gatherers to markets. This is due to the fact that non-timber forest products are extracted under a number of regimes, varying from open access to collective arrangements or contractual arrangements under governmental control. Timber prices, on the other hand are determined in formal markets.

The bio-economic diversity index is given by

$$\sum_i (P_i Y_i / TR)^2 \text{ where } TR = \sum_i P_i Y_i$$

In other words, the index is a weighted index, with values defining functionality. These values may be determined in or outside the market and are treated as weights in the bioeconomic index.

A value of the index close to one indicates that fewer products are being extracted. Hence, a loss of biodiversity is reflected in an increase in the value of the index, which ranges between 0 and 1.This means that the higher the value of index, the lower is product biodiversity. It may bear repeating however, that prices for products are determined under different institutional regimes.

III. The Model

This section sets up the simple and the modified Schaeffer models for timber extraction from forests. It is postulated initially that extraction is determined by effort involved in extraction and the stock. In other words:

Y= f(E, X).

Where Y: Extraction of timber

E: effort involved in extraction X: Stock of timber in the forest

Changes in stock are given by:

$$\dot{X} = rX(1 - X/K) - qEX \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where X: stock of timber

$\dot{X}$: Change in stock in a given time period

rX (1-X/K): Growth in stock in a given time period with

r: net rate of regeneration (difference between increase in and natural depletion from forest stocks)

K: maximum environmental carrying capacity

q: coefficient depicting availability of timber species

Further, Y = qEX: where E: Extraction effort for timber.

We argue that this is justified in the case of extraction from multi-species natural forests which are extracted from. The usual rotational principle of management of single species forests does not apply to the forest as a whole. This expression for forest harvesting is based on an analogous extraction function for fishing. (Gordon,1954,1967; Schaefer,1957 and Clark,1990). In such a function, the composition of products extracted is determined by their value, with the extraction of the high value products being given priority. It is similar to "fishing down the value chain".[4]

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[4] See Kasulo and Perrings (2002) for a similar argument with reference to fishing in Lake Malawi.

Further, to the extent that forest departments have been managing parts of forests for sustainable yield of timber (, *not* for sustainable accrual of all goods and services that forests yield as mentioned above), the model takes it into account by assuming that

$\dot{X} = 0$ since extraction is equal to net regeneration (Since X refers to the stock of timber)

Hence, in the context of timber,

Y= qEX = Xr (1-X/K)…………………..(2)

Therefore X = K(1-qE/r)

And extraction Y = qEK(1-qE/r)…………………………(3)

It depends on E, the effort, and K, the maximum carrying capacity.

The modified model introduces the bio-economic diversity index defined as $\sum_i (P_i Y_i / TR)^2$ where $TR = \sum_i P_i Y_i$. This index is postulated to impact extraction, as a shift factor in the extraction function .[5] To recapitulate, ,the bio-economic index of biodiversity is a weighted index of biodiversity in which prices are used as weights for the different Y_i. A loss of biodiversity is reflected in an increase in the value of the biodiversity index, which ranges between 0 and 1.This means that the higher the value of index, the lower is the product measure of biodiversity.

We   postulate that the effect of this bio-economic diversity on timber productivity is captured by the introduction of an extra term in the timber production function:

$Y = qBEX$ ……………………….(4)

where B is the biodiversity index is a shift parameter implying Y/E = F(B, X).

This   means that the effort involved in timber extraction is inversely related to B. As B decreases (or as biodiversity increases), the extraction function shifts, resulting in a lower

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[5] It is postulated that, though timber is the leading product due to the high value attached to it by the market, the extraction of timber is impacted by the biodiversity of the forest. Many alternative measures of this biodiversity are possible.See Section II for some alternative indices and an introduction to the bio-economic index,

extraction per unit effort. In other words,the model with the biodiversity index yields a lower level of Y for the same level of E since 0<B<1.

Secondly, interest in timber extraction results in a substitution of plantation forests for natural forests changing the ecological feature of the forests as reflected in the mix of natural and plantation forests. Plantations are known to increase both regeneration rates and carrying capacity measured in terms of timber stocks in the short run. The growth function for timber biomass then takes the form:

$$Xdot = rX(1 + eW - X/K) - qEX \dots\dots\dots\dots(5)$$

With W: ratio of plantation area to total forest area

      e: Coefficient for impact of W on growth of timber stock

It is postulated that extraction increases as W, the ratio of plantation area increases. Remember however that B = F(W)……………(5a)

With B increasing as W increases: in other words, as the ratio of plantation area to natural forest area increases, the forests become less diverse.

In other words the model introduces two kinds of effects of decreased biodiversity, the first through a shift in the cost /extraction effort function and the second through a direct impact on extraction through an increased proportion of plantation to natural forest area.

  With this new extraction function and with the assumption of timber extraction following the sustainable yield principle, we get the following growth and sustainable yield functions:

$$Xdot = rX(1 + eW - X/K) - qBEX \dots\dots(6)$$

$$Y = qKBE(1 + eW - qBE/r) \dots\dots\dots\dots(7)$$

IV. Reduced Form of Equations and Estimation of Parameters

In order to estimate the parameters of the modified model given in Section III above, we use the reduced form of Equations (6) and (7) estimated by a method due to Schnute (1987). Under this estimation method Schaefer's production model is reduced to a form

making it amenable to annual data on output and effort, Adapting this method enables us to estimate the parameters from data on timber extraction for the forests of Uttar Pradesh and to examine the impact of biodiversity indices and forest characteristics on the extraction of timber per unit of effort. The aim of this exercise is to examine how timber extraction per unit effort changes with the changing product diversity and ecological nature of the forests.

We define an equation for extraction per unit effort as U, with and without the biodiversity index.

Without the bio-diversity index, $Y=qEX$, $U= Y/E = qX$
And hence $X=U/q$. The growth equation written as:

$$Xdot = rX (1+ eW - X / K) - qEX \quad \cdots\cdots \quad (6)$$

becomes

$$Udot = r(1+ eW - U / qK) - qE \quad \cdots\cdots \quad \cdots\cdots(7)$$

With bio-diversity index B, $Y = qBEX$, with B as an additional explanatory variable,

$$U = Y/BE = qX$$

And hence $X = U/q$

The growth function can then be expressed in terms of U In other words, the equation (6a) given below can be re-written as equation (7).

$$\dot{X} = rX (1+ eW - X / K) - qBEX \quad \cdots\cdots(6 a)$$

$$\dot{U} \, dot = rU (1 - U / qK + eW) - qBEU \quad \cdots\cdots(7)$$
or

$$Udot / U = r - qBE - (r / qK)U + reW \quad \cdots\cdots \quad \cdots\cdots .(8)$$

The above equation (8) can be used to get the reduced form.. It is principally a recasting of the Schaefer model as a dynamic, discrete-time, stochastic model.   This leads to a differential equation in U_t once E is known. Such a formulation is important for the forest model since it can then ignore the population biomass and concentrate on extraction for which data is more readily available. The single equation (8) encompasses the purpose of equations (1), (2) and (3), on the assumption that extraction is based on the principle of sustainable management for at least one of the forest products, in this case timber.   The total effect of forest biodiversity on extraction over time based on this management principle focusing on one of many products is then examined through an estimation of the reduced form equations and their parameters.

This estimation can be done in a number of ways. Some of these are, the generalized Ricker models and the family of Deriso-Schnute models as discussed in Ludwig and Walters (1989)[6]. The Schnute model(1977) has some advantages compared to other models. It predicts extraction per unit effort from an integrated continuous dynamic model and captures better the dynamic nature of extraction- effort intractions. we use this method to obtain the estimating equations and their parameters.

 By adding time subscripts and integrating from t-1 to t to equation (8),we get:

$$\ln(U_t / U_{t-1}) = r - q E_t - (r/qK) U_t + re W_t + e \dots \dots .(9)$$
$$\ln(U_{bt} / U_{bt-1} = r - q E_t - (r/qK) U_{bt} + re W_t + e \dots \dots (10)$$

 with U being defined with and without biodiversity index as U_t and U_{bt} respectively. In both cases, it is interpreted as extraction per unit of effort. The estimating equation and the parameters indicate the nature of the relationship between extraction per unit of effort,

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[6] See Ludwig and Walters (1989). Such discussions on the accuracy and suitability of different models have taken place mainly with reference to the fisheries literature.

, and the character of the forest as exemplified by W_t and U_t. The logarithmic form of the equation places some restrictions on the interpretation of the coefficients. However, it ensures that the time series estimation is consistent and efficient as it provides an approximation to ensuring that stationarity of the series is tested for.

V.1 Forests and Forest Policy of Uttar Pradesh

The model and the reduced form equations obtained in Sections III and IV are estimated using time series data for the north Indian state of Uttar Pradesh. The geographic area of this state is 29.441 million hectares and forests comprise 17.29 % of the area. Most of these forests are concentrated in the northern region of the state (forming part of the Himalayas in the newly constituted state of Uttaranchal (formed in 2000)). However, the south and south west of the erstwhile state of Uttar-Pradesh (UP) too have considerable amounts of forest area.. These forests, including both natural and planted forests can be categorized in two ways, by density size class or by forest type. The latter is sometimes referred to as the Champion and Seth (1968)classification. According to this classification, there are seven major forest types in UP viz. Tropical Moist Deciduous, Tropical Dry Deciduous, Tropical Thorn, Sub-tropical Pine, Himalayan Dry Temperate, Sub-alpine and Alpine Forest,. The geographic distribution of these depends on altitude above sea level, rainfall and other climatic considerations. Each forest type further differs in its species diversity and its density characterization.

Dense forests are here defined as those with a canopy cover of more than 70%, open forests as those with canopy cover between 40 and 70% and scrub as those with canopy cover of 10 to 40 per cent. In the state of UP dense forests constitute 67.63per centof the total forest area while open forests and scrub cover the rest, i.e. 32.37%. Changes in land use take place on a continuing basis. In the latest assessment (of 1996) total change in the dense, open and scrub forest as compared to an earlier assessment (1994) is indicated. Dense forests have lost in all 56 sq. kilometers of area, open forests have

gained 78 sq kilometers, scrub has gained 7 square kilometers and non-forest area has lost 29 square kilometers. The matrix depicting these changes is given in the appendix[7]

Whereas dense forest has been converted mainly into open forest, there has been some conversion of small areas of dense forests into non-forest too. On the other hand a larger area of open forest has been converted to scrub or non-forest. The other major change, the conversion of 50 sq km area of non-forest area into open forest can be attributed to newly emerging plantation forests.

Further, the absence of any single dominating species in the dense forest category shows that these forests are of a highly diverse nature. This justifies the use of the functional form specified above. These forest types are obviously more species- diverse than the open and scrub forests. The open forests, created as a consequence of plantation activity tend to be less diverse . Further, a large part of plantation activity has been concentrated in the post 1980 era. Total area under plantations upto 1997-98 is estimated to be 1.793 million hectares[8] Of this, only 0.661 million hectares had been planted prior to 1980. It is possible therefore, that the species composition of the plantation forests is dominated by a few fast growing species.

In UP, the practice of clear felling was prevalent till 1980 This meant that a whole forest stand could be cut down and new trees planted in   its place. Since 1980, restrictions on clear felling activity were introduced . The Forest Act banned selective felling. In its place came the the practice of 'dry drifting'. Under this practice, there exists now a complete ban on green felling and only those trees that die a natural death after maturity are allowed to be cut down. This practice has led to a rise in the cost of timber extraction from natural forests in the state since the economies of scale which accompany management of forest stands are no longer available. The blanket ban on green felling in the state leaves lesser scope for the timber collector (private as well as public) to attempt cost saving effort on transportation cost and/or labour cost. As a result,

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[7] See appendix Table ---.
[8] The year wise data on plantation is obtained from UP Forestry Statistics Book, 1998 and from the records of Joint Director, North zone, Shimla.

timber extraction from natural forests is further discouraged and plantation activity is expected to increase.

V.2 Sources of Data

For an estimation of the model (explained in Section IV), data are needed on annual output i.e. timber extraction, effort, bio-economic indices and ratio of plantation area to forest area for the period 1975 to 1998 . This section explains the sources and limitations of the data.

Output

The output of timber per unit effort is the dependent variable in the reduced form equation. Output is defined as extraction of timber from forests in Uttar Pradesh from 1975 to 1999[9]. It is measured in physical quantities i.e. cubic metres per annum.

Extraction Effort

Cost of extraction of timber (obtained from the Annual Reports of the Forest Corporation of Uttar Pradesh) is approximated by the costs of felling and transportation to the forest gate or the warehouse. In order to be used to approximate the physical cost of extraction of timber in the forest and therefore the "effort" variable in the model, it is deflated to take account of the difference between the monetary and real "wage rate" of the workers. We deflate the effort series using an index constructed from the information on minimum wages in the forestry and logging department of the state[10].

Output per unit effort U_t is obtained by dividing the total extraction of timber by the total effort in extraction of timber, defined as real cost. Effort in timber extraction is in Rs. Lakhs and the extraction of timber is in cu m. So the units for U_t are Cubic metres per rupee of effort.

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[9] Data for the extraction of timber is obtained from the Forest Corporation of Uttar Pradesh. See Appendix for the data tables.

[10] See Appendix for the data series and details of the procedure.

Out put per unit effort adjusted for biodiversity is defined as U_{bt} which is U_t further adjusted by the biodiversity index (bioeconomic diversity). Since the index is a fraction, the units for U_t and U_{bt} are the same. The dependent variable for the model is R constructed by taking the ratio of the current over the lagged value of U, both U_t and U_{bt}. The logarithmic value of R is used in the model.

The bio-economic index of biodiversity is constructed by taking a value-weighted average of extraction of timber and non-timber forest products. This requires, information on non-timber forest products, in addition to timber.For this purpose, the data on quantity of NTFP and timber extraction was collected from the bulletins of the Indian Council for Forestry Research and from the Forestry Statistics of India (1987-94, 1995, 1996 and 2000). For the weighted index of biodiversity annual sales values of the various NTFP and timber were collated from balance sheets of the Uttar Pradesh Forest Corporation. The time series of the index is constructed using 26 years of data (1974-1999). The values of the bioeconomic index for these years are shown in Graph I in the Appendix.

The ratio of plantation area to total forest area depicts the ecological status of the forests . Data on area under plantations is obtained from Forest Survey of India(FSI), both from their published bulletins, "State of Forest Report" and from unpublished data obtained from their records[11]. The ratio of plantation to total forest area is increasing over the years. Starting from a ratio as low as 0.12 in the eighties. It has now gone up to 0.48.

We use equations (9) and (10) as the estimating equations with data constructed as above and relating to forests in the north Indian state of Uttar Pradesh forests for the period 1975-2000. Using the above data sources, we estimate the following two equations derived from equations (9) and (10) above:

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[11] We are thankful to Mr Anup Singh and Mr. Rajesh Kumar of Forest Survey of India, Dehradun for making this data available.

$R_t = \ln(U_t/U_{t-1}) = f(E_t, U_t)\ldots\ldots(9a)$

$R_t^* = \ln(U_{bt}/U_{bt-1}) = f(E_t^*, U_t^*)\ldots\ldots(10a)$

$R_t^* = \ln(U_{bt}/U_{bt-1}) = f(E_t^*, U_{bt}^*, W_t)\ldots\ldots(11a)$

VIII Results and Discussion

The dependent variable, timber extraction per unit of effort is adjusted for the bio-economic index mainly to highlight the significance of the use value of biodiversity. Our interest is in focusing on the impact of different explanatory variables on this use value with respect to a range of goods and services. Further, the equation could be estimated with and without the ecological characteristics of forests as one of the explanatory variables. We give below both sets of estimates

Eqn	Constant	Coefficient of Effort E	Coefficient of U_{bt}	Coefficient of U_t)	Coefficient of W	Adjusted R^2	F statistic	DW-statistic
I	-0.96065 (-2.417)	0.000433 (1.6459)		0.000689 (2.605)		0.168	3.43 (0.0502)	1.85
II	0.3192 (0.7664)	-0.2492 (-1.668)	.0008 (1.1215)			0.184	3.72	2.07
III	-5.229 (-2.5458)	0.0853 (0.4495)	0.00169 (2.9636)		8.7454 (2.8354)	0.558	5.12	1.97

Equation I is:

$$R_t = \ln(U_t/U_{t-1}) = f(E_t, U_t)\ldots\ldots(9a)$$

Equation II is:

$R_t^* = \ln(U_{bt}/U_{bt-1}) = f(E_t^*, U_t^*)\ldots\ldots(10a)$

Equation III is:

$R_t^* = \ln(U_{bt}/U_{bt-1}) = f(E_t^*, U_{bt}^*, W_t)\ldots\ldots(11a)$

where

$$R_t^* = \ln(U_{bt}^{*^*}/U_{bt-1}^*)$$

$$U_{bt}^* = E_{bt}^*/B_t \; i.e, extraction \quad peruniteff \quad ort, adjustedfo \quad rbioeconom \quad icindexofd \quad iversity$$

$$E_t^* = E_{3t}^* \; i.e. Effortofti \quad mberextrac \quad tion$$

$E_t = Effortofex \quad tractionpe \quad ryear$

$U_t = Extraction \quad peruniteff \quad ortunadjus \quad tedforecon \quad omicindexo \quad fbiodivers \quad ity$

$W_t =$ Ecological Characteristics of the forest (ratio of plantation area)

The above equations are selected from a set for representing the best fit. Further, the logarithmic form of the dependent variable and its being the ratio of two years observations ensure that the results are robust even though we do not conduct formal tests for stationarity of the time series.

In equation I, the ratio of extraction per unit effort is sought to be explained only by the effort variable It is found, as expected, that extraction of timber per unit effort increases with increase in effort, E,. However, the explanatory power of the model is low since the adjusted R^2 is only 0.168.

Equation II introduces the variable extraction per unit effort adjusted for biodiversity index as an explanatory variable. While this turns out to be positively and significantly related to extraction, the explanatory power of the model is still low.

Equation III introduces two variables, U_{bt} the biodiversity adjusted extraction (per unit effort) and W standing for the ecological characteristics of the forest (as indicated by the share of plantation area in the total area). This formulation results in a greater

explanatory power of the model with the coefficients of both W and U_{bt} being significant.

The equation can be written as:

$$\text{Log}(U_{bt}/U_{bt-1})= r+.0853\ E_t+.00169*U_{bt} +8.7454**W_t$$

Where * indicates significance of the co-efficient at 5% level and ** denotes significance at the 1% level.

The results indicate that:

- Effort E_t is not, by itself, a significant determinant of trends in extraction in this formulation

- Extraction increases over time as the plantation area increases.: the coefficient of W is positive and significant. Since W is inversely related to the level of biodiversity in the forest, a decreasing biodiversity due to a larger ratio of plantations leads to rising trends in extraction .

- Change in extraction per unit effort over time increases as U_{bt} increases. Further, assuming E to be constant, U_{bt} (defined as Y/BE) may increase under the following conditions with respect to the biodiversity index B.

    a. a With a rising B (which means decreasing biodiversity) , if Y rises faster than B (extraction rises faster than biodiversity goes down) U_{bt} increases and change in extraction of timber increases in future time periods. A rising extraction with decreasing biodiversity of the forest pushes the system towards a state in which increases in extraction take place at an increasing rate.

    b. bWith a falling B (which implies increasing bio-diversity): U_{bt} could decrease provided Y is not rising faster than B is decreasing lead to a decreasing trend in extraction in following periods of time. In such a situation, U_{bt} shall rise if extraction increases faster than B and this shall lead to the same results as under (a).

    c. A constant B (constant levels of bio-diversity) increases in U_{bt} are determined by changes in Y

The results suggest that , in the absence of variables representing the plantation area and bio-diversity corrected stocks, the explanatory power of the model is low, even though extraction is seen to be significantly impacted by effort. If, however, the ratio of plantation area and biodiversity adjusted extraction are introduced as explanatory variables, interesting results with respect to the trend of extraction over time are obtained As stocks of woody biomass increase, extraction increases. A decrease in bio-diversity of the stock may be accompanied, under a certain set of circumstances, with a rising trend in extraction, and at a rising rate as explained above:. However, an increased biodiversity, may imply a decreasing trend in the extraction in the future provided that present extraction Y does not rise at a rate faster than the rate of increase in the biodiversity. These two results seen together are, we believe, significant. They point to the fact that policies aimed at increasing plantation increase short run timber extractionII Further, if biodiversity increases, the impact on future extraction of timber depends on relative rates of change in biodiversity and extraction per unit effort. It is clear that trade-offs between timber extraction and existence of bio-diverse forests providing a variety of goods and services.

While some of these consequences have been observed as stylized facts by foresters and others, this paper constitutes one of the few instances in which time series data from a developing country with extensive forests of different types has been used to set up an econometric model and test the hypothesis.

APPENDIX 1

Indices of Biodiversity

A biodiversity index is a mathematical expression to measure species diversity in a community. Diversity indices provide information about the community composition and take the relative abundances of different species into account to quantify the diversity.

1. Shannon-Weiner Index:

This diversity index is based on information theory, i.e. the measure of order (or disorder) within a particular ecosystem.

$$H' = - \sum_{i=1}^{S} (p_i) (\log_2 p_i)$$

Where **H** = Information content of sample, Index of species diversity, or Degree of Uncertainty, **s** = Number of species, p_i = Proportion of total sample belonging to **i**th species.

Measures of Evenness

The maximum Shannon-Wiener index for a given number of species can be calculated as:

$$H'_{max.} = \log_2 S$$

The minimum Shannon-Weiner index for a given data set can be calculated as:

H' = log N (N – S + 1 / N) [log (N – S + 1)]

Where:

S is the number of categories or species

N is the total number of observations

The evenness of the sample can be calculated by the following equation:

$$J' = H' / H'_{max}$$

2. Simpson's Index

Simpson's diversity index (D) is a simple mathematical measure that characterizes species diversity in a community. The proportion of species i relative to the total number of species (p_i) is calculated and squared. The squared proportions for all the species are summed, and the reciprocal is taken:

$$D = 1 / \sum_{i=1}^{S} p_i^2$$

For a given richness (S), D increases as equitability increases, and for a given equitability D increases as richness increases. Equitability (E_D) can be calculated by taking Simpson's index (D) and expressing it as a proportion of the maximum value D could assume if individuals in the community were completely evenly distributed (D_{max}, which equals S – as in case where there was one individual per species). Equitability takes a value between 0 and 1, with 1 being complete evenness.

$$\mathbf{E_D} = \frac{D}{D\max} = \mathbf{1}\,/\,\sum_{i=1}^{S} \mathbf{p_i}^2 \times \frac{1}{S}$$

Where:

S is the total number of species in the community (richness)

p_i is proportion of S made up of the ith species

E_D equitability (evenness)

3. Island Biogeography Theory

An assumed species area relationship is used to estimate the biodiversity in forests as shown by the following equation

$$\mathbf{S = CA^Z}$$

Where, S is the number of species, A is the area and C is a parameter that depends on the type of species, its population density and the biogeographic region. 'Z' determines the shape of the species area curve and has values between 0.16 and 0.39 for most regions of the world. Z factors have inverse relationship with the area under consideration i.e. as the area under consideration increases the Z factors become smaller. Islands have Z factors of around 0.35 whereas continental areas have Z factors of about 0.20. Though, the factors affecting the values of Z are still incompletely known.

4. Biodiversity Threshold Index[12] (for measuring biodiversity from land use viewpoint)

The focus of conventional forest management has, more often than not, been on timber production and functions almost exclusively at the stand level whereas the regional planners consider some broader issues of the forest sector. In complete contrast, the measurement of biodiversity from the sustainability perspective requires the inclusion of all spatial scales.

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[12] This section is drawn from Angelstam, P. and Bleckert, S.

The biodiversity threshold index tries to look at how different owner categories use different combinations of different management methods in a landscape.

5. Bio-economic Diversity Index:

Figure 1: Index of Bio-economic Diversity: 1974-2000.
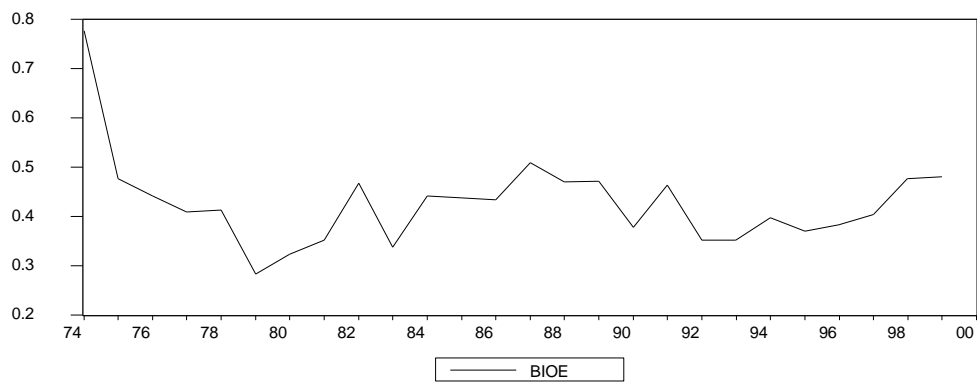
APPENDIX 2: DATA TABLES AND PROCEEDURES

TABLE I: CHANGE MATRIX FOR FOREST LAND IN UTTAR PRADESH

Type of forest → Converted to / Originally	Dense	Open	Scrub	Non-forest
Dense		+39	0	+9
Open	+100		+3	+50
Scrub	0	+21		+8
Non-Forest	+4	+15	+19	
Total gain in Area	+56 = +(100 + 4) - (39+9)	-78 = +(39 + 21+15)_ (100+3+50)	-7= +(3+19) - (21+8)	+29 = +(9 + 50+8) - (4+15+19)

A positive sign denotes an addition to the forest type given in the column. Total gain in area in each forest type is given in the last row

TABLE II: EXTRACTION OF TIMBER IN UTTAR PRADESH: 1975- 99. AND ITS COST, UNDEFLATED AND DEFLATED

Years	Cost of extraction of Timber (Rs. Lakhs)	Cost of extraction of Timber deflated by minimum wage index (Rs. Crores[*])	Extraction (m^3)
1975	186.68	1.71	81288
1976	147.39	1.24	134053
1977	108.09	0.84	130450
1978	185.17	1.31	229913
1979	262.25	1.70	272822
1980	444.79	2.65	305415
1981	667.59	3.59	478574
1982	280.36	1.37	631481
1983	264.11	1.17	588840
1984	722.91	2.92	589154
1985	857.32	3.15	634706
1986	817.12	2.73	579753
1987	928.81	2.82	601071
1988	710.32	1.96	485698
1989	791.63	1.99	471534
1990	1007.15	2.30	444411
1991	1714.46	3.55	496197
1992	1278.46	2.41	344938
1993	1389.24	2.38	447585
1994	1314.13	2.05	303071
1995	1868.68	2.65	383656
1996	1202.16	1.70	195236
1997	1101.03	1.56	328607
1998	1717.03	2.43	476480
1999	1789.63	2.53	452680

Source: Uttar Pradesh Forest Corporation.
Note: The minimum wage index is constructed with 1974 as base year in which the minimum wage is pegged at 100 and thus the deflated cost figures are effectively in Rs.crores.

FIGURE 1: TOTAL EXTRACTION OF TIMBER (CUBIC METER)

Total extraction of Timber
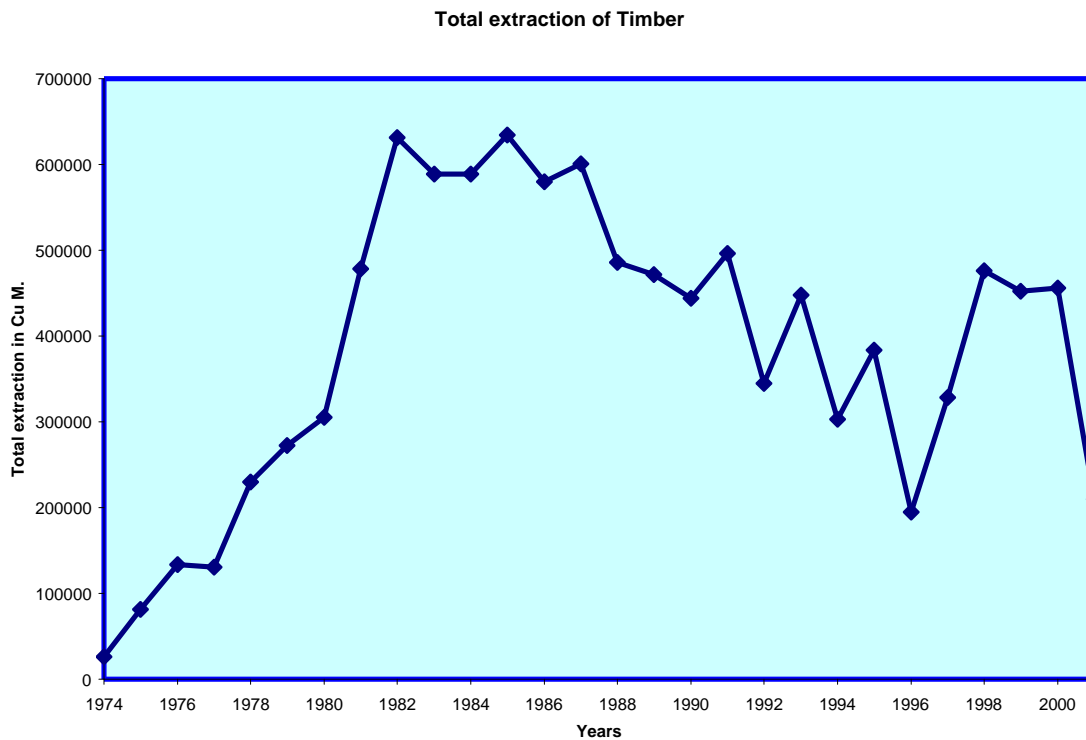
Deflation by wage series.

The minimum wages are available in different distant slots of time. E.g. in 1963, in 1987 and in 1995 and often the jump in minimum wages is huge. In order to smooth the rise in minimum wages and make it a proxy index of wage inflation we have intrapolated and extrapolated data for the rest of the years using compound interest formula. Then 1974 was taken as the base year to construct the index of wages. The Cost of extraction is then deflated by this series.

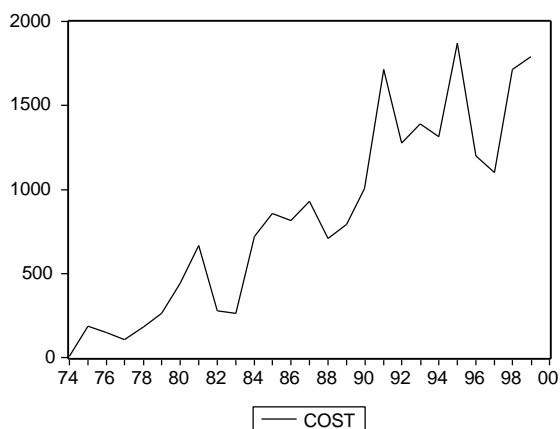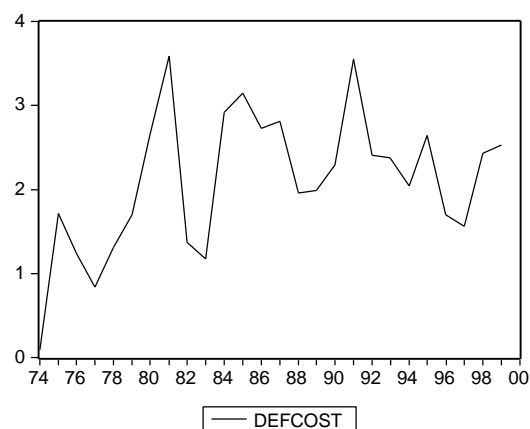FIGURE 2 MONETARY COST   FIGURE 3 DEFLATED COST

The deflated cost series is contains a feebler rising trend compared to the monetary cost series, which shows that costs have escalated in physical units and not just due to wage inflation.

Data Sources:

The data for the minimum wages in the Forestry and logging department is obtained from volumes of The Labour Statistics of India; extractions cost figures are taken from the balance sheets of the Forest Corporation of Uttar Pradesh.

The physical cost is often called Effort in the standard literature. In the standard literature on fishing efforts and catch effort is considered in physical units, i.e. number of ships sent for fishing etc. In the case of forestry however a physical measure of cost was achieved by deflating the cost of extraction of timber by the minimum wage series obtained from the Forestry and Logging Department data, Government of India.

FIGURE IV : Ratio of Area under Plantation to Forest Area.
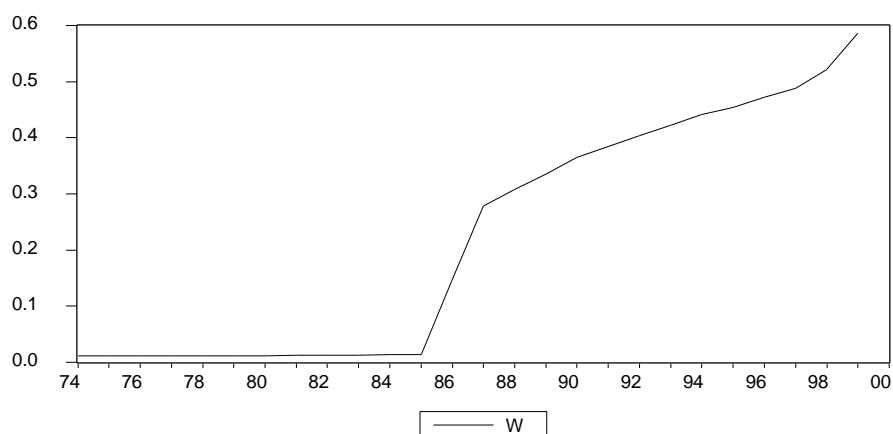
Note that the graph looks horizontal to the axis upto 1980 because there was very limited plantation in the early years compared to the late 80's and the 90's.

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