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# When the Theory Is Not Enough – Valuation of Forest Resources with "Efficiency" Prices in Practice

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**Abstract**

In resource accounting, simple theoretical models built upon efficiency prices have been developed to capture changes in social welfare generated by natural resources. We examine whether changes in market stumpage prices, as proxies for efficiency prices, have actually reflected changes in the physical timber inventories in Finland and Sweden during the past seventy years. Cointegration and unit root tests show that no long-term equilibrium relationships exist between the timber prices and stocks. After identifying a potential reason for the result, the basic theoretical growth model is slightly elaborated to provide a more appropriate framework for measuring net domestic product for the forest sector.

## 1. Introduction

Forests have been the most extensively empirically studied renewable resource in resource accounting. The theoretical foundations of the accounting framework lie in the work of Weitzman (1976), which Solow (1986) elaborated with natural resource stocks. Weitzman provided a theoretical basis for national accounting, showing that the Hamiltonian *along an optimal growth path* as comprehensive current net domestic product (NDP), in terms of utility, is a stationary equivalent of future consumption, or "a flow-equivalent proxy for future welfare". Since Weitzman's seminal paper, interest in the principles of welfare accounting has become considerable, and the Hamiltonian-based Hicksian measure of income has been actively discussed in the context of green accounting.[1] What is common to the theoretical analyses is that calculation of national product has been derived in a normative, optimizing framework, where it is taken as given that prices support the optimum path. However, this can be an unrealistic assumption, which can undermine the usability of any suggested welfare indicators in a "non-optimal" real world. Resource accounting practitioners should at least be aware of this concern when starting accounting for changes in the natural resource base.

In practice, when adjusting national accounts for the use of natural resources, it is recommended that, if possible, market prices should be used in the valuation. For example, it is stated that in valuation of European forests "The stumpage price is the price that should be used for the valuation of standing timber" (Eurostat, 2000). This is in line with the European System of Accounts (ESA) which prefers market prices as ESA's basic reference for valuation (ESA §1.51; Commission of the European Communities, 1996).

The main purpose of this article is to investigate whether changes in the forest resource stock are in fact reflected in market prices. This is of interest, since the resource accountant wants to measure the value of the change in volume of standing timber. The theory of natural resources indicates that not only physical changes in the stock of capital but also changes reflected in the shadow price of a natural capital stock are of importance. The shortcut of using market prices as proxies for resource rents in accounting may be problematic, if there is reason to suspect that market prices are not

[1] See, e.g., Mäler (1991) and Hartwick (1990), which are based on Weitzman (1976). See also, e.g., Aronsson and Löfgren (1997), Dasgupta and Mäler (1999). A good overview of much of this discussion is given by Heal and Kriström (2001). Hultkrantz (1992) and Vincent and Hartwick (1997) include examples of empirical studies in resource accounting in forestry.

optimal from the point of view of natural resource management. This will be the case when market prices reflect something other than the opportunity cost of using up a unit of the resource. Externalities and lack of property rights often lead to pricing failures. In addition, the harvestable timber stock is reduced in conservation areas by forest protection measures, which is clearly reflected in stumpage prices but not in the total forest inventories. Moreover, without further investigation it is difficult to claim that stumpage prices as such reflect the quantity or quality of non-market forest amenities.

To gain an understanding of how the accounting prices behave with respect to stocks in practice, we analyze annual data on timber stocks and stumpage prices in Finland and Sweden over the last seventy years. Forestry has been important for economic development in both of these countries, and a systematic resource inventory began early in the $20^{th}$ century. Stumpage prices should capture raw material values of forest biomass, or the resource rent, relatively well, because property rights have always been clearly defined. Since time series of the length used here are rather unique in forestry, it is relevant to analyze the data using econometric methods.

Recent empirical analyses using modern time series econometric methods to study natural resource rents include Hultkrantz (1995). Similarly, the work of Hotelling (1931) has been applied to the "mining" of the *renewable forest resources* by Barnett & Morse (1963), Brown & Field (1978), Lyon (1981), and more recently by Seroa da Motta & Ferraz do Amaral (2000), who have analyzed time paths of timber prices and/or depreciation of stocks both theoretically and empirically. None of these studies include resource stocks in the analyses. Nevertheless, as Hyde & Amacher (1996) note, prices are believed to reflect the development of resource stocks over time: "upward price adjustments are the natural and expected results of drawing down natural forest stocks, and we expect continued upward price adjustments until the new price is sufficient to justify investments in long-term forest management." Forest resources and their monetary valuation should be especially important now that forest reserves are included as wealth, or assets, among other capital stocks in European national accounts (Commission of the European Communities, 1996).

The paper is organized as follows. In section 2, we first derive a theoretically consistent and socially optimally valued consumption for an economy, or 'green' national income, measured in the Hicksian sense. Sections 3 and 4 then treat methods, data and empirical estimation. Results are presented in section 5. This is followed by the discussion of implications for theoretical modeling in section 6 and by conclusions in section 7, which completes the paper.

**2. The theory**

We derive a hypothesis of a relationship between socially optimal prices and resource stocks to be tested in our empirical analysis. This is to show rigorously why the use of market prices (stumpage prices) as proxies for shadow prices of renewable resource stocks (forests) has important consequences for welfare interpretations of extended national accounts. We use a simple dynamic model typically used in the theoretical literature, since it is claimed that simple models can provide a simple method for deriving an income measure that incorporates the depletion of natural and environmental resources (see, e.g., Pemberton & Ulph 2001, Hartwick 1990). However, it is not totally unproblematic to interpret the results from the theoretical models as prescriptions for applied national accounting. [2] If there is reason to suspect that prices do not support the optimum path, the analytical welfare theoretical foundation of greened accounts does not hold. This makes the welfare interpretation of green NDP extremely difficult. We do not know what we are measuring after all, since we do not know the "true" objective function of the economy.

We model forests as a source of renewable, but potentially depletable, timber harvested for use as raw material. By focusing on the *timber scarcity* aspect, we consciously leave out other important aspects from the model, such as environmental services provided by forests. In fact, we develop a forestry accounting framework for annual timber production which is allocated to annual consumption (harvest) and annual investment (change in forest assets).

Let us consider an economy which at time $t$ uses a renewable resource stock, $V(t)$. The stock is increased by natural growth, $F(V(t))$[3], and depleted as the resource is used, $h(t)$. We assume that the resource extracting sector of the economy is a price taker in both the input and output markets, and the output price is denoted by $p(t)$ and the harvesting costs by $c(t)$. The net revenue from harvests, $[p(t)-c(t)]\cdot h(t)$, is discounted over time by a constant interest rate $\delta > 0$. Since the natural resource

[2] This issue has previously been raised in Brekke (1994) and Aaheim and Nyborg (1995).
[3] Our analysis is limited to a resource stock of a size for which the following assumptions on natural growth hold true: $F_V>0$, $F_{VV}<0$. This is a realistic assumption as long as the aggregate stock is increasing, i.e., the share of old growth is not dominating.

stocks are of particular importance when constructing environmental accounts, the economy's objective is to maximize the discounted integral of profit *subject to the resource constraint* dV(t)/dt = F(V(t)) – h(t), which captures the dynamics of the stock variable. The current value Hamiltonian can be written as $H(t) = [p(t)-c(t)]\cdot h(t) + \varphi(t)\,[F(V(t)) - h(t)]$, where the current value shadow price of the resource stock is $\varphi(t)$.[4] The optimal infinite time solution must satisfy the following conditions:

(1) $\partial H(t)/\partial h(t) = p(t) - c(t) - \varphi(t) = 0$

(2) $d\varphi(t)/dt = \varphi(t)[\delta - dF(V(t))/dV(t)]$

(3) $dV(t)/dt = F(V(t)) - h(t)$

Equation (1) is a social optimality condition; it says that the marginal profit from harvesting one unit of the resource, (p(t)-c(t)), must equal the current value shadow price of a unit of the resource in situ.

In our forestry sector accounting framework, when the resource use is optimal according to (1), the Hamiltonian yields net domestic product, NDP $=\varphi(t)F(V(t))$, which is equal to nature's annual production. Growth of the resource stock is then valued by its shadow price, which is the current opportunity cost of the standing forest stock. The shadow price captures the value of future harvesting benefits and determines the optimal conservation of stock. According to the derivation above, the shadow (efficiency) price should react to different stock levels as a signal about scarcity. If the economy does not happen to be in a steady state[5] initially, the shadow prices and, accordingly, the accounting prices will change over time. Given the functional form of the resource growth, $F(V(t))$, and the equation of motion for the co-state variable, $d\varphi(t)/dt=\varphi(t)[\delta - dF(V(t)/dV(t)]$, this is illustrated in Fig. 1. If the interest rate exceeds the marginal growth rate of the resource stock, $\delta > F_{V(t)}$, it is viable to invest less in the renewable resource stock which will, as a result of increased consumption, decrease. Meanwhile, the shadow price of the resource stock will increase, although

[4] Since we describe the accounting framework as a maximization of discounted profit, or the value added from the forestry sector over time $\int_0^{\infty} [p(t) - c(t)] \cdot h(t)e^{-\delta t}dt$ the Hamiltonian is linear with respect to harvests. We show in Appendix that our formulation can alternatively be presented in a utility maximization framework.

[5] By definition, a steady state equilibrium ($h_{ss}$,$V_{ss}$,$\varphi_{ss}$) occurs where $\dot{h} = \dot{V} = \dot{\varphi} = 0$ implying that $F_{V_{SS}} = \delta$ and $h_{ss}=F(V_{ss})$, and the NDP becomes $\varphi_{ss}\cdot F(V_{ss})$.

at a slower rate, as can be seen from equation (2). The social ‘scarcity price’ of the resource will increase until the resource growth has reached a steady-state level corresponding to the interest rate such that $F_{V(t)} = \delta$.

[Place Figure 1 here]

It should be noted that the increase in shadow price reflects a change in the productivity of the asset, or the interest rate. The productivity change differs from market variations in asset prices, which do not necessarily reflect changes in shadow prices. According to the derivation, the socially optimal shadow price should react to different stock levels in order to signal about scarcity. Given the welfare interpretation assigned to the Hamiltonian in the green accounting literature, it is important to investigate empirically whether the market prices used as proxies for shadow prices support the efficient optimum path in reality. The most obvious proxy for the shadow price in case of timber resources is market price (see, e.g., Eurostat 2000, Kunte et al. 1998). We study the relationship between rents and resource stocks econometrically using a unique set of time series data on forest stocks and timber prices in Finland and Sweden from the last seventy years. Data sets spanning such a long time period potentially reflect the changes in the natural resource dependency of the economies. During the past ten years, information and communication technology has challenged the position of the forest sector in both countries. Hence, our analysis may be visionary also from the point of view of economic history in attempts to understand the nature of the concerns and the state of restructuring processes in today’s developing world, which is dependent on raw material exports. (See also, e.g., Atkinson and Hamilton, 2001.)

## 3. Methods

As is well known from the analysis of time series, statistical inference based on conventional t and F tests is invalid and the results obtained may be entirely spurious for relationships including non-stationary time series data. A time series is denoted I(0) when it is stationary in levels and non-stationary and integrated of order *d* (I(*d*)) when it must be differenced *d* times in order to achieve (weak covariance) stationarity (see, e.g., Banerjee et al. 1993, Maddala and Kim 1998). Cointegration is essentially based on the idea that there may be co-movement between trending economic time series such that there is a common equilibrium relation which the time series have a tendency to revert to in the long run. In the short run, there can be divergence from equilibrium. Thus, even if certain time series themselves are non-stationary, a linear combination of them may exist that is stationary. In the present case, we are interested in testing whether there is an equilibrium relation in the long run between timber price and timber stock series over the last seventy years.

Johansen's full information maximum likelihood method has become by far the most popular method in empirical estimation of cointegration relations. The method is efficient because of the incorporation of both long- and short-run effects (i.e. adjustment to equilibrium) in the empirical model structure. In this study, the cointegration rank is determined by estimating a two-dimensional VAR($k$) model (see Johansen, 1995, p. 11):

(4) $$x_t = A_1 x_{t-1} + \ldots + A_k x_{t-k} + \mu + \varepsilon_t, \quad t = 1,\ldots,T,$$

where $x_t$ is a vector of empirical variables, here the timber stocks and timber prices in Finland or Sweden. In (4) $\mu$ is a vector of constant terms, $k$ is the lag length ($k$ = 1,...,N) and $\varepsilon_t$ is a vector of error terms assumed to be NID(0,Ω). Equation (4) is re-parameterized in error-correction form (see Johansen 1995, p.89) as:

(5) $$\Delta x_t = \Gamma_1 \Delta x_{t-1} +, \ldots, + \Gamma_{k-1} \Delta x_{t-k+1} + \Pi x_{t-k} + \mu + \varepsilon_t, \quad t=1,\ldots,T$$

where $\Delta x_t$ is an I(0) vector. In (5) the constant term, $\mu$, can be restricted to cointegration space in the estimation if it is assumed that there is no linear drift in $x$. $\Gamma_1,\ldots, \Gamma_{k-1}$ and $\Pi = - I + \Pi_1 +,\ldots,+ \Pi_k$ are coefficient matrices. Γ describes the short-term dynamics of the process and Π is the matrix of long-run coefficients, which can be decomposed into a matrix of loading vectors, α, and a matrix of cointegrating vectors, β, such that $\Pi=\alpha\beta'$. The cointegration vectors define the stationary linear combinations (if there are any) of the variables in $x_t$. The rank test in the Johansen procedure is used to determine whether there is a cointegration vector, β, in this bivariate case, i.e. rank (Π) = $r = 1$. A likelihood ratio based trace test for testing cointegration rank, r, where the null hypothesis $H_0$ : r = 0 against $1 \le r \le 2$.

## 4. Data

Time series data for *Finnish timber prices* cover the period from 1911 to 1998. Nominal coniferous sawlog stumpage prices were deflated by the Finnish wholesale price index. The *Finnish timber stock* data were constructed by adding net growth (growing stock increment estimated periodically in the context of regular timber inventories minus *drain,* or losses in growing stock due to felling, silvicultural measures and natural mortality) to the previous stock level annually. As a consistency check, these observations were compared to timber inventory values, which are regularly updated and re-measured for the whole country approximately every 8 to 10 years. As some inconsistencies were observed in the earliest Finnish timber stock data, only data starting from 1938 were used in the analysis.

We used the *Swedish timber stock* data that are estimated from inventory values and annual harvests in a similar manner as in Finland. The stock figures are reported in official statistics as five year sliding averages for the period 1926 to 1998. Coherent *Swedish stumpage price series* were more difficult to find. Like Hultkrantz (1995), we used a number of different data sources in order to obtain a price time series that covers the whole period 1926-1998. Streyffert (1960) reports stumpage prices for public forests covering the period 1926-1958, which are complemented by official statistics on stumpage sales on public and private land for the later period 1955-1998. Thus, the chained time series for the period 1926-1998 is based on sales on public lands for the years 1926-1951, on both private and public lands for the years 1952-1972 (where we employ the mean of these prices), and on private land only for the years 1973-1998. Although the data are based on somewhat varying samples, we shall henceforth assume that this time series represents an accurate estimate of the market value of standing timber for the years 1926-1998. As a Swedish deflator for the time span under consideration, we have used the Cost of Living Index for the years 1926-1935 and the Consumer Price Index for 1935-1998. Since the Living Cost Index is the predecessor of the Consumer Price Index in Sweden, and it has been used also in an earlier study by Hultkrantz (1995), we presume that we do not have a problem of two different deflators.

In Fig. 2 real stumpage prices show strong business cycle fluctuations and fitted trends in stumpage prices show about 1% increase per annum in both countries. Logarithms of the time series were used in the econometric analyses.

[Place Figure 2 here]

The data plotted in Fig. 2 show that inventories of timber in both countries increased steadily over the period studied. What should be noted here is that the official inventories of physical stock also include forestland where other land uses significantly restrict timber production (military use, national parks, reserves etc.). This part of the standing stock obviously contributes to the total quantity of the stock but is not subject to market transactions. However, the bulk of these large unharvested areas are located in northern forestlands, the economic importance of which is rather limited, and they account for some 5 % of the total timber stock in each country (Fridman 1999, Miljömålsrådet 2002, SOU 2000, Finnish Forest Research Institute, 2001). In addition, public investments in building up forest road networks have considerably decreased the regional differences in the physical access to forest reserves and in unit costs of harvesting and transportation.

**5. Results**

Prior to cointegration analysis, Augmented Dickey Fuller (ADF) (Dickey and Fuller 1979) unit tests were performed for individual time series using software package PcFiml 9.0. Various lags of differenced dependent variables were used to remove autocorrelation from the residuals of test equations by applying the strategy that selects the highest lag with a significant t-value. The results in Table 1 indicate that the null hypothesis of non-stationarity could not be rejected for inventory series in Sweden or Finland, although it could be rejected for their first differences at the 1% and 5% level, respectively. For stumpage price in Finland, non-stationarity could be rejected at the 5% level. For Swedish stumpage price, the null-hypothesis of non-stationarity was not rejected.

**[Place Table 1 here]**

The analysis suggests clearly that Swedish timber price and inventory are integrated of order one, and thus, it is important to test for possible cointegration between the series. In contrast, Finnish stumpage prices can be regarded as stationary at the 5 % level which would indicate that no cointegration can exist.

Using Johansen's cointegration method, a two-variable VAR-model was estimated for Sweden. Since inventory data for Sweden are trending, a specification allowing for an unrestricted constant in cointegration regression was chosen. As the method is fairly sensitive to the number of lags used in the analysis, different models were compared using both residual tests and a procedure incorporating sequential decreases in the number of lags in choosing a suitable model. Using these criteria, a two-lag model was found to be sufficient to remove residual price autocorrelation in the Swedish model. The chosen VAR-models were tested to be acceptable statistical formulations regarding residual autocorrelation, normality and heteroscedasticity (results available from authors upon request).

**[Place Table 2 here]**

The existence of long-run equilibrium relationships between timber price and inventory were tested using the Johansen's trace test, and the results are reported in Table 2. For Sweden, no co-integration could be detected irrespective of the different model specifications. It can be concluded that, in the long run, no tendency for timber prices and inventories to reach a steady state equilibrium was found.

To draw overall conclusions from the empirical analysis, the assumptions of the theoretical model and their implications for the empirical analysis need to be discussed. At first sight, a natural extension to the analysis presented above would be to consider the nature of price formation on the roundwood markets. As indicated by earlier empirical studies, market prices are derived from the prices of wood-based final products independently of the sizes of the regional timber inventories (see e.g. Brännlund et al. 1985, Toppinen 1998). If markets are integrated internationally, the size of a forest stock in a single country is too restrictive an explanatory supply side factor, and it is possible that market prices reflect the marginal productivity of the resource stocks only *globally*.[6] If

[6] Trade in roundwood has been modest throughout the study period in both countries. On average net export from Sweden was 1.0 million cubic meters 1926-1974 and net imports to Sweden were 3.7 million cubic meters 1975-1998 whereas net export from Finland was about 3 million cubic meters 1920-1964 and net imports to Finland were about 5 million cubic meters 1965-1998. Source: See "Data sources" in the references. As a referee pointed out, the product trade also is important but it is difficult to capture its impact on stumpage prices due to differences in industry structures in different countries. Closer analysis of this impact is therefore out of the scope of the present paper. Most importantly, if roundwood prices are formed internationally and depend also on the international formation of wood product prices, it is even more evident that valuing national timber stocks with market prices restrict the welfare interpretation of greened accounts.

this is so, there is little point of deriving national green accounts, which are aimed to be used as indicators of the effects of public environmental policy interventions *nationally*. In this respect, it is worrisome that stumpage prices do not seem to have reflected the size of national forest reserves, since in the presence of global markets, the objectives of green accounting become even more challenging as there is no simple way of splitting up a global welfare into national welfare measures.

## 6. Implications for theoretical modeling

Our empirical analysis suggests that market prices for timber are not cointegrated with the size of forest resource stocks. In the case of Scandinavian forests, it appears as if resource accountants currently have access to data that are wrong measures of shadow price or physical stock, or both. This empirical complication is often assumed away in theoretical social planner models, and national accountants do not “press welfare interpretations of calculated GNP and NNP too hard” by making calculations at *observed* prices and quantities (see Hartwick p. 296, 1990). Perhaps this is a concern for environmental accountants if the principal purpose of developing national resource accounting is to provide information for environmental policy decisions.

A typical reaction to our result is that the theoretical model we use is misspecified. Non-decreasing prices and increasing physical forest stocks perhaps reflect preference and technology changes, increasing availability of substitutes, etc. But this critique is exactly our point. It is our deep concern that movements in market prices do not reflect the physical marginal productivity of the national stocks, but that other factors – not included in the simple theoretical models – are more influential. [7] This is claimed to be well understood by resource economists. However, we are not quite sure whether this is the case when resource accounting is conducted. It would be a serious flaw to use market prices as proxies for the shadow prices of the resource stocks in resource accounting, since a green net national product derived using "flawed" market prices cannot be given any welfare interpretation. The immense problems associated with obtaining data to estimate the suggested welfare measures accurately are not discussed in theoretical analyses.[8] Still, critical problems

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[7] Of course, the criticism can also be faced by recognizing that the suggested changes should have led to corresponding changes in harvests which in part should have been materialized in changes in timber stocks.
[8] For a brilliant view on the importance of the issue, see Eisner (1989).

emerge in estimation of many key relations in resource economics, and the theory should not abstract from such problems if any practical method of green national accounting is to be based on theoretical results. Is there anything that could save a pure, simple theory in our case?

Let us try to illustrate our point with our forest resource data. Finnish and Swedish forest stocks have been increasing and forest growth has also increased, but prices have not decreased. Therefore, welfare – expressed as $\varphi(t)F(V(t))$ – must have increased over time. However, the theoretical growth model of section 2 does not accurately capture a phenomenon of simultaneous increases in the stock and its shadow price. Can we still claim that welfare has increased? In fact, it is possible to keep to the simple theoretical sector model and by making a minor modification, show that it is optimal to increase the resource stocks whose market value is increasing.

It is crucial to note that forest growth is generated by natural production, $F(V(t))$, to explain growth and to measure value added generated in timber production. One possibility is that there has been a systematic, upward shift in the forest growth function explaining the non-decreasing stocks and prices as illustrated in Fig. 3. Consequently, the growth function would take the form $F(V(t), E)$ where $E$ would capture factors shifting the production such that $F_E>0$. Empirically, it is an interesting issue whether $E$ is an exogenous or endogenous variable. Nitrogen deposition from the air functioning as fertilizer would be an exogenous factor whereas silvicultural efforts would represent endogenous effects.

[Place Figure 3 here]

What is important for our analysis is that exogenous and endogenous effects have different implications for welfare accounting. An exogenous impact would be "pennies from heaven", and no adjustments for valuing annual production would be needed. In contrast, active, silvicultural efforts such as replanting are not provided for free, but have an opportunity cost in the form of intermediate consumption. In modeling, this logic can be described such that a certain proportion of revenues from harvests, $\alpha h(t)$, is allocated to finance expenditures of silvicultural measures, or $F(V(t), \alpha h(t))$. Carrying out the same optimization exercise as in section 2 with the modified growth function, we end up with the Hamiltonian yielding net domestic product,
$\mathrm{NDP} = \varphi(t)F(V(t), \alpha h(t)) - \varphi(t)h(t)\alpha F_{h(t)}$. Now the latter component is an adjustment factor

decreasing the level of welfare since the increase in the natural growth has materialized at the expense of (other) consumption and investments.

As a final remark, we emphasize that we have consciously excluded from our analysis different amenities provided by the forest stock. Without further investigation it is difficult to claim that stumpage prices reflect the quantity or quality of non-market forest amenities. A natural follow-up question is whether the value of positive externalities provided by the renewable forest stock – if not captured by the stumpage prices – can be proportional to the market prices. One could argue that market prices implicitly capture some of the amenity value and therefore they have been rising over time. However, amenities make the welfare interpretation of green NDP even more difficult. We do not know what we are measuring after all since we do not know the "true" objective function of the economy. If market prices partly reflected amenity values then it would not be correct to value them separately due to a risk of double counting. That is why we stress the importance of clearly defining what the valuable resource stock is, and then finding a market price or other economic measure that actually captures the scarcity of this stock.

## 7. Conclusions

There does not seem to be much empirical work that tries to check whether pricing of natural capital is consistent with the efficiency prices used in the theoretical frameworks for resource accounting. Our analysis is a rare attempt in the direction of bridging the gap between the theory and practice in scrutinizing the justification of welfare theoretical interpretations from empirical accounting exercises.

The most conservatively formulated conclusion from our analysis is a minimum requirement that environmental accountants should always establish a verifiable relationship between market prices and the shadow value of the stock. Our results point to an absence of any connection between stumpage prices and the growing timber stock in Sweden or in Finland. A theoretically inconsistent behavior of increasing timber stocks and non-decreasing prices suggests that valuation of net growth of forests by market prices would lead to an overestimation of future welfare. We have identified one potential factor that explains the inconsistency and that is relevant for renewable resources in general: the importance of studying how the natural growth is achieved. If an increase in the natural growth has required costly measures, the expenditures should be deducted from annual income otherwise the level of welfare generated by natural resources is overestimated.

Lacking equilibrium relationship between a resource stock and its efficiency price would be unfortunate from a social point of view, if sustainable use of resources were a concern in managing resources. More importantly, ignoring the validity check of assumptions made in the theory undermines the usability of the empirical measures for analysis of welfare. This may be even more worrisome if this is true also for those economies that are today in their early stage of economic development and dependent on natural resource assets and need appropriate sustainability indicators most.

**Appendix**

Utility is derived from consumption of good c(t), which is produced by using a renewable resource as input (h(t)). The production function is denoted by g(h(t)), the renewable resource stock by V(t), and the resource growth by F(V(t)).

Maximize $\int_0^\infty U(c(t))e^{-\delta t}\,dt$

subject to $c(t)=g(h(t))$

$dV(t)/dt = F(V(t)) - h(t)$

Then the current value Hamiltonian is

$H(t) = U(c(t)) + p(t)[g(h(t)) - c(t)] + \varphi(t)\,[F(V(t)) - h(t)]$,

where *p(t)* is the Lagrangian multiplier, and *φ(t)* is the current value shadow price of the resource stock. The optimal infinite time solution must satisfy the following conditions:

(1) $\partial H(t)/\partial c(t) = U_{c(t)} - p(t) = 0$

(2) $\partial H(t)/\partial h(t) = p(t)g_{h(t)} - \varphi(t) = 0$

(3) $d\varphi(t)/dt = \varphi(t)[\delta - dF(V(t))/dV(t)]$

(4) $dV(t)/dt = F(V(t)) - h(t)$

Linearize the Hamiltonian and use the f.o.c.

$H(t)^* = U_{c(t)} \cdot c(t) + p(t)g_{h(t)} \cdot h(t) - p(t)c(t) + \varphi(t)\,[F(V(t)) - h(t)] = \varphi(t)\cdot F(V(t))$

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## Data sources

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Statistiska Centralbyrån, SCB, Stockholm (Statistics Sweden)
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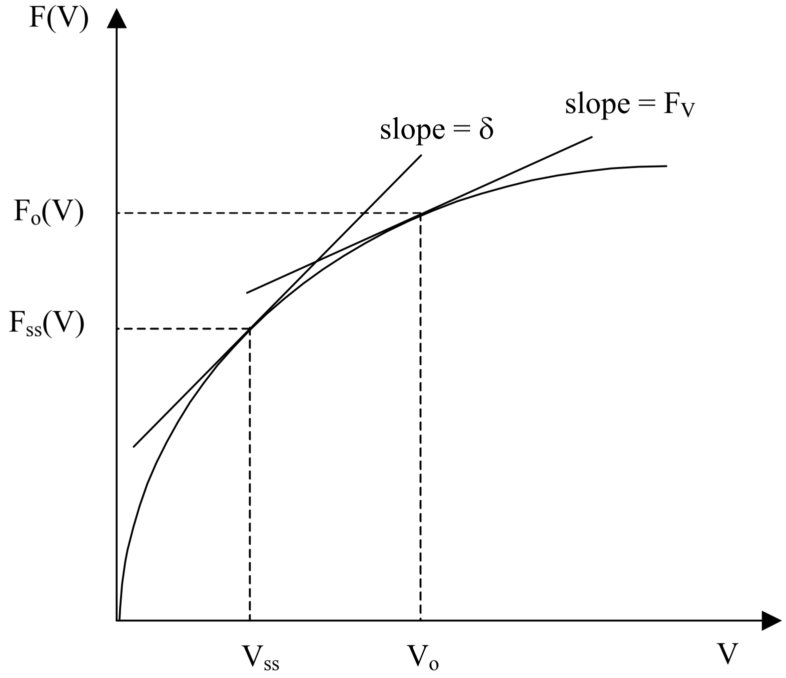
Legend to Figure 1.

Changes in the values of state and co-state variables over time.

Figure 1. Huhtala, Toppinen and Boman



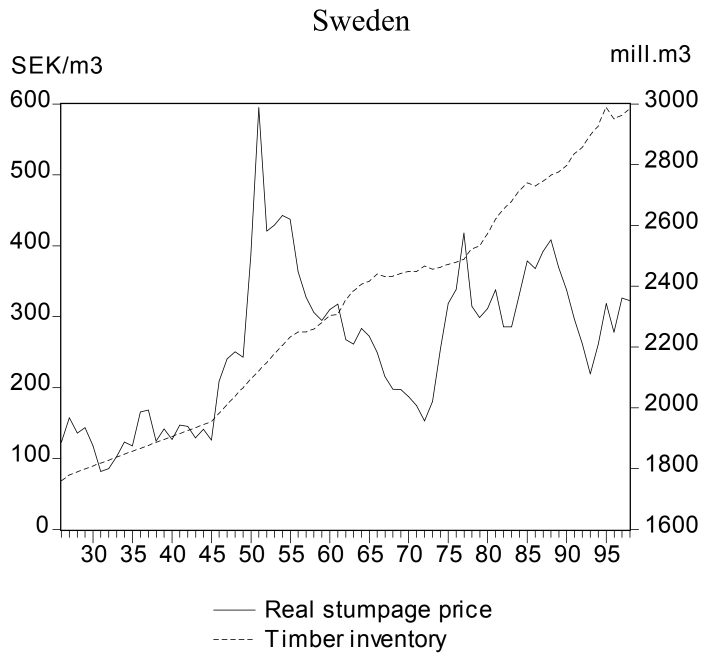

Note: Subscripts ss refer to steady state; $\varphi(0) = \varphi_o$ and $V(0)= V_o$, and $d\varphi/dt = \varphi[\delta - F_V]$.

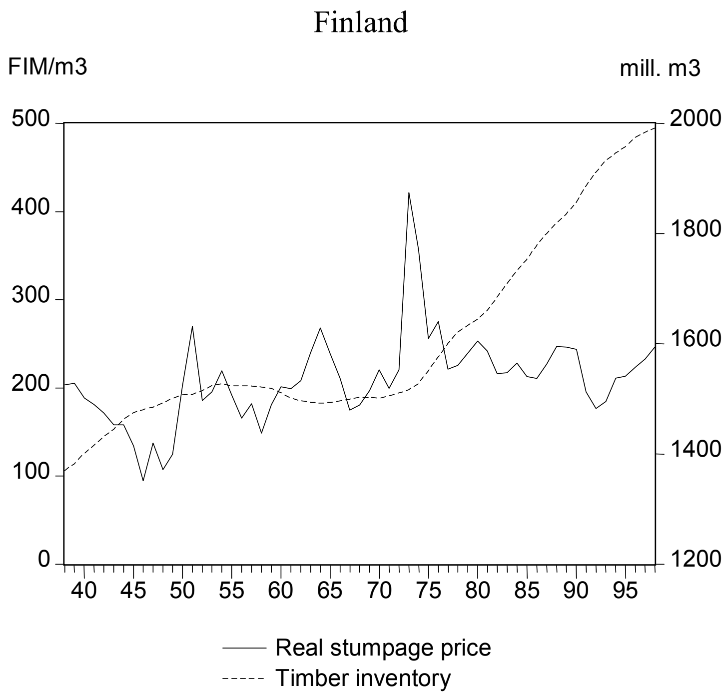
If initially $F_V < \delta$ then $dV/dt<0$ and $d\varphi/dt>0$, and $\varphi_{ss} > \varphi_o$, and $V_{ss} < V_o$.

Legend to Figure 2.

Timber inventory and real stumpage price in Sweden (1926-98) and Finland (1938-98).

Figure 2. Huhtala, Toppinen and Boman



Legend to Figure 3.

Impacts of an upward shift in the forest growth function.

Figure 3. Huhtala, Toppinen and Boman

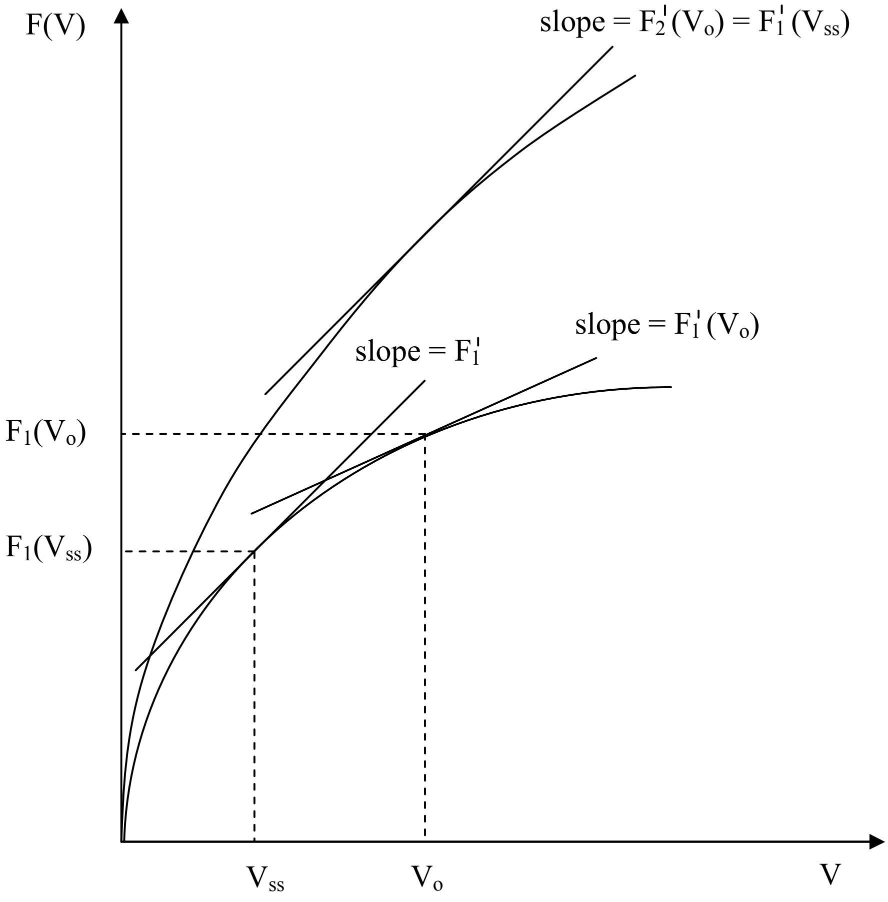


**Table 1.** ADF-test results for timber price and inventory series. T indicates the inclusion of a trend in test equation and number i, k=i the number of lagged differences in the equation. *(**) denotes the rejection of null hypothesis of non-stationarity at 5 % (1 %) level (see e.g. Dickey and Fuller 1979).

| | Levels of time series | 1st difference of time series |
|---|---|---|
| **Sweden (1926-98):** | | |
| Timber inventory | -2.31 (T, k=2) | -4.17** (k=1) |
| Stumpage price | -1.91 (k=0) | -7.90** (k=0) |
| | | |
| **Finland (1938-98):** | | |
| Timber inventory | -2.07 (T, k=1) | -1,89* (k=1) |
| Stumpage price | -3.05* (k=0) | -8.35** (k=0) |

**Table 2.** Results from Johansen's tests for cointegration rank, r, between timber price and inventory. The null hypothesis is no cointegration.

| | **Cointegration rank** | |
|---|---|---|
| | r=0 | r≤1 |
| **Sweden (1926-98):** | | |
| Eigenvalues | 0.15 | 0.00 |
| Trace test-value | 11.33 | 0.03 |
| 95 % critical value | 15.4 | 3.8 |