9 Combining multimarket and general equilibrium welfare measurement in applied CBA. A case study of the Swedish forest sector

Bengt Kriström

9.1 Introduction

This paper uses a multimarket model to measure the benefits and costs of a large, albeit hypothetical, forest conservation project in Sweden. My main aim is to suggest the use of a particular approach, rather than to provide a detailed analysis of the benefits and costs. The scale of the program[1] is chosen such that it is likely that prices within the sector will be affected. A similar analysis to the one undertaken here is in Geijer et al (2011), who considers an identical, if larger reform, focusing on the market consequences. A main difference, which also is the aim of this paper is to show how non-market benefits can be added to the welfare analysis.

In general terms, the analysis is partly motivated by the fact that large-scale reforms that may affect non-market values in a material way, raises questions about how willingness-to-pay (WTP) should be estimated. It is particularly difficult to estimate WTP when income changes with the project. Therefore, a methodology that allows consistent estimates of WTP along an equilibrium path might be useful in cases when a project affects a particular sector of the economy. While computable general equilibrium (CGE) models can also be used to address the issues, the multi-market approach has some advantages when a policy affects a particular sector of the economy. First of all, data limitations may make a CGE-analysis infeasible or at least more difficult, when data on the necessary level of aggregation is not available. Second, the multi-market approach makes the welfare analysis transparent and intuitive. Third, it is possible to explore in detail key parameters (such as substitution elasticities and price elasticities) that drive the differences between a partial and multi-market equilibrium approach. One can employ a basic result in welfare economics, showing that the all welfare impacts can be summarised in one market. It is as if the analysis can be

[1] The scale is similar to a (later rejected) proposal put forward by a Government Commission in 2020 on Swedish forest policy, SOU 2020:73 ”Stärkt äganderätt, flexibla skyddsformer och ökade incitament för naturvården i skogen med frivillighet som grund”, Swedish Government official remit, 30 November 2020

summarised in one demand-supply diagram, even though the policy affects many markets. This involves using demand and supply curves that are slightly different from the usual partial equilibrium curves, whence they include changing conditions on other markets. The multi-market approach also has its downsides, since one must make assumptions about which prices that are to be exogenous to the model. Altogether it is simply one empirical approach that is useful in certain contexts.

I apply the suggested approach to Swedish forest policy discussions for two main reasons. First of all, it is well established in the literature on non-market valuation that forest conservation in Sweden is associated with significant non-use values[2]. Secondly, the forest sector remains a key industrial sector of the Swedish economy, providing significant export revenues and employment opportunities. Consequently, the trade-offs that need to be made are consequential at the scale considered here.

The paper is structured as follows: section 9.2 presents the theoretical models, in which I delineate benefits and costs for projects affecting the forest sector. To set the stage I begin with a simple model of the forest sector and derive general equilibrium welfare measures, including the case of unemployment. I then present a more detailed multi-market model of the forest sector, and obtain welfare measures in this more complex setting. The multi-market model integrates secondary market effects that all can be measured at the primary market. As noted, this is a standard result that carries over to the setting. The main theoretical contribution is to suggest how costs and benefits can be estimated consistently in a multimarket model. I then turn to the empirical application, detailing the data on the cost and benefits in section 9.3, summarizing market and non-market studies. The empirical results are presented in section 9.4. The beginnings of a more complete cost-benefit analysis are presented in section 9.5. The paper ends with some remarks on how the analysis can be developed further.

9.2 Cost-benefit analysis of forest sector projects

9.2.1 A simple model

I begin with a simple case[3] and then turn to a more detailed multi-market model. The first model can be seen as a approximate CBA of "small" forest projects, in which I

[2] Therefore a direct method (i.e. a survey) is the only way to estimate the total benefits.
[3] Based on Johansson & Kriström (2018)

also include a discussion about how to handle unemployment. In the second model, I develop welfare measurement in multimarket models in more detail.

Consider a representative household that owns all the firms in the economy. A forestry firm (f) produces sawlogs and pulpwood. I will later expand on this model to include additional activities, but this workhorse model will ultimately be the one I use for the empirical part. The sawmill and the pulp & paper industry each produce a final product that is consumed by the household. To simplify the presentation, I let the household consume the forest products instead of using them as input products in the household's production of utilities. The indirect utility function is written:

$$V = V(p^c, p^{pw}, p^{st}, w, \Pi), \tag{1}$$

where p^c is a composite good, p^{pw} denotes the price of the pulp product, p^{st} the price of the sawlog product, w the wage level, Π denotes total profit income, and the price of the numeraire is normalized to one and suppressed henceforth.

The output of the forestry firm is assumed to be exogenously determined and is used to generate a cost-benefit rule. Let us define profits as

$$\pi = p^{st} \cdot y^{st} + p^{pw} \cdot y^{pw} - w \cdot l^f, \tag{2}$$

where p^{st} (p^{pw}) denotes the price of sawlogs (pulpwood), y^{st} (y^{pw}) the quantity of sawlogs (pulpwood) and l^f its demand for labour, which for simplicity is the only factor of production.

The two sectors of the forest industry, pulp & paper (sawmills), uses pulpwood (sawlogs) and labor (for now, I ignore other inputs). Their profit functions are functions of respective input and output prices. We will detail them in the next section. The representative firm producing the composite good is assumed to use labour as the only factor of production.

Let us now marginally change the supply of sawlogs and pulpwood. A simple cost-benefit rule of profitability of such a project is given by the following expression:

$$\frac{dV}{\lambda} = dCV = p^{st} \cdot dy^{st} + p^{pw} \cdot dy^{pw} - w \cdot dl^f, \tag{3}$$

where λ denotes the marginal utility of income and dCV denotes the marginal compensating variation, i.e., the willingness to pay for the project (CV denotes the compensating variation). Notice that all quantity and price effects on other markets vanish, since price is assumed to be equal to marginal cost and all markets are in equilibrium. This is a useful rule of thumb, which consequently is true also in general equilibrium. CBA appears to be partial equilibrium, but it is based on general equilibrium foundations.

This is clear when the price changes are small. However, a change in timber supply may be so large that it affects prices more than marginally. Using equation (1) define the compensating variation that makes the household indifferent to the change:

$$V\left(p^{c^1}, p^{pw^1}, p^{st^1}, w^1, \Pi^1 - CV\right) = V\left(p^{c^0}, p^{pw^0}, p^{st^0}, w^0, \Pi^0\right), \quad (4)$$

where a index 1 (0) denotes the final (initial) level.

As long as the forest industry sets $p^i = MC^i$, i.e., applies marginal cost pricing, we can ignore value added changes outside the primary sector. It should be noted, however, that the equilibrium paths for the two wood variants are difficult to estimate. The equilibrium conditions of the different markets must be used to simultaneously solve the equilibrium prices as functions of the exogenous variables. More on this below, where this problem is solved using an estimated equation system.

Alternatively, we can integrate equation (3) along the equilibrium path to obtain CV. The integrals reflects areas under ”Bailey”, or observed supply curves from which we deduct the cost of labor. This version assumes that all markets are competitive. The key point of writing CV in this way is that we can summarise all effects in the primary market.

Finally, I illustrate how unemployment is usually handled in CBA by generalizing equation (3) as follows:

$$\frac{dV}{\lambda} = dCV = p^{st} \cdot dy^{st} + p^{pw} \cdot dy^{pw} - w \cdot (dL^f - dL^u) - w^R \cdot dL^u, \quad (5)$$

where $w^R \leq w$ is the reservation wage or the minimum compensation the unemployed person is willing to accept and $dL^u \geq 0$ is the number of unemployed people who are employed in the project. The cost of recruiting the otherwise unemployed is *positive* as long as the reservation wage is strictly positive but normally lower than the cost of recruiting a person who also has a job in the alternative case.[4]

To conclude: it is easier to conduct a CBA if one can focus on a single market, rather than analyzing either highly aggregated forest industry markets or a myriad of markets for consumer products. In addition, in most cases the project under analysis can be expected to be so small that prices are left more or less unaffected. An analysis based on equation (3) is then sufficient to approximate the socio-economic value of the project. But there are cases when such assumptions may be useful to relax, at least to some extent. We thus turn to a case when prices are thought to change significantly in a given sector using a slightly different approach.

9.2.2 Multimarket welfare measurement

The theory behind multimarket welfare measurement is presented in e.g. Just et al (2005), which in turn is inspired by Bailey (1954). The methodology has wide applicability, see e.g., Alston & James (2002) (agriculture), Ankarhem (2005) (forest sector) and Geijer et al (2011) (climate policy). The model presented in this section is a generalization of Brännlund & Kriström (1996). The main extension is the embedding of the multimarket welfare measure into a general equilibrium structure in an approximate manner, where I include non-market goods in the welfare measure. In this way, it is possible to obtain measures of benefits and costs that take into account sector repercussions. At the outset, it should be stressed that some prices are held exogenous and therefore the measures are not general equilibrium in the conventional sense.

Forest owners use labor l^{f}, energy e^{f} and one fixed input K^{f} to supply (s) three different outputs, $\mathbf{y}^{\mathrm{f}} = \{y^{fw}, y^{pw}, y^{st}\}$, where y^{fw} is fuelwood. I assume a constant returns to scale short-run technology, with the standing stock of timber being fixed in the short-run. The forest technology is implicitly given by $H^{\mathrm{f}}(y^{fw}, y^{pw}, y^{st}, -l^{f}, -K^{\mathrm{f}}) = 0$, where H^{f} is a transformation function.

Maximizing profits subject to the technology gives the profit function in forestry

$$\Pi^{\mathrm{f}}(p^{fw}, p^{pw}, p^{st}, w^{l}, ; K^{\mathrm{f}}). \tag{6}$$

[4] Theoretically, a project can also affect unemployment elsewhere in the economy, although it is difficult to see how such effects can be ”tracked” in an evaluation of a small project.

With the assumptions laid out by Diewert (1973), there is a duality between the transformation functions and the profit function, and I henceforth use the latter. Supply functions for forest owners are obtained via Hotelling's lemma;

$$y^{fw} = \frac{\partial \pi^{\mathrm{f}}}{\partial p^{fw}} \tag{7}$$

$$y^{pw} = \frac{\partial \pi^{\mathrm{f}}}{\partial p^{pw}} \tag{8}$$

$$y^{st} = \frac{\partial \pi^{\mathrm{f}}}{\partial p^{st}} \tag{9}$$

I next introduce three activities that buys inputs from the forestry-sector; $\mathtt{nf} = \{dh, pp, sm\}$. District heating (dh) uses inputs $\{x^{fw}, l^{dh}, e^{dh}, K^{dh}\}$, where l^{dh}, e^{dh} is the demand for labor and other energy inputs than firewood in district heating, respectively; K^{dh} is a quasi-fixed input. This sector produces heating services y^{dh}. The pulp industry (pp) employs energy, labor with prices $\{l^{pp}, e^{pp}\}$ and a quasi-fixed capital stock input (K^{pp}) to produce an output denoted y^{pp}. Finally sawmills combine variable inputs sawlogs, labor, energy together with a quasi-fixed input, to supply an output y^{sm}.

let Π^{nf} denote the profit functions in the non-forestry sector that buys forestry output. These functions are obtained by maximizing profits subject to the respective technologies. The forestry products are demanded by the nf firms, and their demand functions are given by Hotelling's lemma

$$x^{fw} = -\frac{\partial \pi^{dh}}{\partial p^{fw}} \tag{10}$$

$$x^{pw} = -\frac{\partial \pi^{pw}}{\partial p^{pw}} \tag{11}$$

$$x^{st} = -\frac{\partial \pi^{dh}}{\partial p^{st}} \tag{12}$$

9.2.2.1 Sector equilibrium

I assume supply equal to demand in the market for forestry products. The remaining markets outside of the forest sector are all assumed to be in competitive equilibrium with exogenous (relative to this model) output prices. Thus, labor markets and energy markets are all in equilibrium throughout the change considered here. The prices on these and other suppressed markets change are assumed to change only marginally due to the project. I normalize the number of firms to one and focus on the equilibria in the system, which I write as, suppressing all but the own-prices in the demand and supply functions,

$$x^{fw} = y^{fw} \tag{13}$$
$$x^{pw} = y^{pw} \tag{14}$$
$$x^{st} = y^{st} \tag{15}$$

other markets are suppressed and assumed to be in equilibrium throughout. In principle, the system can be solved for the equilibrium prices $\{p^{fw}, p^{pw}, p^{st}\}$, as functions of the exogenous variables in the model. I will use this fact when computing welfare measures in the next section.

9.2.2.2 Profit changes due to conservation

I consider a conservation project, which I model as a reduction of the forest capital stock using a project parameter α. I interpret a reduction of forest capital as a way of withdrawing a certain fraction of available forest capital from the market. Thus, a small project is modelled as $K^{\mathrm{f}} \cdot d\alpha$ and a non-marginal project $K^{\mathrm{f}} \cdot \Delta\alpha$. Observe that while the stock of forest is not a part of the profit function in the nf-firms, it will affect the equilibrium prices in an indirect way.

I assume that all markets are in equilibrium throughout the change induced by the project. Let • denote the exogenous prices of the model and $p^* = \{p^{fw}(\bullet, \alpha \cdot K^{\mathrm{f}}), p^{pw}(\bullet, \alpha \cdot K^{\mathrm{f}}), p^{st}(\bullet, \alpha \cdot K^{\mathrm{f}})\}$.

Let $\alpha^0 = 1 \rightarrow \alpha^1 \in (0,1)$ represent the project and let ”0” denote profits in the status quo. Then,

$$\Delta\pi^{\mathrm{f}} = \pi^{\mathrm{f}}\left(p^*(\alpha^1), \bullet; \alpha^1 \cdot K^{\mathrm{f}}\right) - \pi^{\mathrm{f}^0} \tag{16}$$
$$\Delta\pi^{l^{dh}} = \pi^{dh}(p^*(\alpha^1), \bullet; K^{dh}) - \pi^{dh^0} \tag{17}$$
$$\Delta\pi^{pp} = \pi^{pp}(p^*(\alpha^1), \bullet; K^{pp}) - \pi^{pp^0} \tag{18}$$
$$\Delta\pi^{st} = \pi^{st}(p^*(\alpha^1), \bullet; K^{sm}) - \pi^{sm^0} \tag{19}$$

Thus, $\Delta\pi^j = \int_1^{\alpha^1} K^{\mathrm{f}} \frac{\partial\pi^j}{\partial\alpha} d\alpha, j \in \{\mathrm{f}, dh, pp, sm\}$. Using the equilibrium conditions, we obtain:

Proposition 1. *Let* $\alpha > 0$ *be a project parameter used to exogenously change the stock of forest, such that* $dK^{\mathrm{f}} = K^{\mathrm{f}} \cdot d\alpha$. *The sum of the profit changes (*$\equiv \Delta\Pi$*)* ***in the forest sector*** *under the project* $\alpha^0 = 1 \rightarrow \alpha^1 \in (0,1)$ *is*

$$\begin{aligned} \Delta\Pi &= \Delta\pi^f(\alpha) + \Delta\pi(\alpha) + \Delta\pi(\alpha) + \Delta\pi^{l^{dh}}(\alpha) && (20) \\ &= \int_1^{\alpha^1} K^{\mathrm{f}} \frac{\partial\pi^{\mathrm{f}}(p^*(\alpha), \bullet; \alpha \cdot K^{\mathrm{f}})}{\partial\alpha} d\alpha && (21) \end{aligned}$$

Proof.

$$\begin{aligned} \Delta\Pi &= \sum_{s \in f \cup nf} \Delta\pi^s && (22) \\ &= \sum \int_{K^{\mathrm{f}^0}}^{K^{\mathrm{f}^1}} \frac{\partial\pi^f}{\partial p^i} \frac{\partial p^i}{\partial K^{\mathrm{f}}} dK^{\mathrm{f}} + \sum \int_{K^{\mathrm{f}^0}}^{K^{\mathrm{f}^1}} \frac{\partial\pi^{nf}}{\partial p^i} \frac{\partial p^i}{\partial K^{\mathrm{f}}} dK^{\mathrm{f}} + \int_{K^{\mathrm{f}^0}}^{K^{\mathrm{f}^1}} \frac{\partial\pi^f}{\partial K^{\mathrm{f}}} dK^{\mathrm{f}} && (23) \\ &= \int_1^{\alpha} \frac{\partial\pi^f}{\partial\alpha} K^{\mathrm{f}} \cdot d\alpha && (24) \end{aligned}$$

The key idea is that the induced price changes net out, assuming that the markets are in equilibrium throughout the change. Thus, the sum of the profit changes in the sector is obtained by integrating along the equilibrium path. The basic idea has been well articulated by Carbone & Smith (2013):

> The comparisons [...] parallel the distinctions between consumer surplus for a price change measured along a partial versus a general equilibrium demand function (see Just, Hueth and Schmitz (2004), pp. 327-330). The general equilibrium demand function for a particular good measures the consumer surplus due to an intervention - say a new commodity tax on that good - by evaluating that good's demand at the general equilibrium prices for all goods

The project studied here is different from the one studied in the original paper by Brännlund & Kriström (1997), because the project affects three markets simultaneously. In their study, the initial perturbation was limited to one market. Their key result was that the sum of profits in the forest sector could be measured in one market, provided that one integrates along the equilibrium path. This is a standard result, that is useful for empirical application.

9.2.3 Non-market goods

We now proceed with an extension of multimarket welfare measurement by introducing households, so that I can disentangle benefits and costs in the natural way. I abstract away from foreign ownership. Thus, any change of profits in any firm in the forestry sector will accrue to the domestic consumer I simply assume that the price changes in other sectors than forestry are marginal; importantly, the output prices for firms using inputs bought from forest owners are assumed fixed. In effect, actors in the forestry sectors acts as if the prices exogenous to this model are given. For general equilibrium applications using CGE-modelling involving non-market goods, see e.g., Carbone & Smith (2013) and Smith & Qiang (2018).

One advantage with the approach taken here is that there is no need for calibration of the model in the status quo. Indeed, for a CGE-model to replicate the benchmark, parameters need to be set such that supply is equal to demand (assuming that the benchmark is interpreted as a general equilibrium, which is typically the case). One way to accomplish this is to use expenditure data combined with assumptions on key elasticities. If a non-market activity is active in the benchmark, then parameters of the utility function need to be set such that the model can replicate the initial equilibrium, including the non-market good. For example, in the benchmark equilibrium of the Carbone & Smith (2013) model (an extension of Goulder & Williams (2003)), there are acidific deposition from nitrogen- and sulphur oxides. These affect fish, scenic vistas and tree cover. Calibration involves an augmented income-concept, such that income includes the value of an environmental quality endowment. Thus, in the benchmark, spending is equal to income, using a virtual price on environmental quality. These calibration concepts are not needed in this framework.

It should be stressed that the main focus is the benefits and costs of forest policy, not, as in Carbone & Smith (2013), substitution patterns in general equilibrium when public goods are non-separable in the utility function. In this paper there is only one public good and I do not explicitly study interactions with private goods. Also, environmental quality does not enter per se in the production functions in my case.

Assume that the individual appreciates the preservation of forests, represented by an index z, so that an increase in z increases utility. Other goods are for simplicity assumed to be a composite good with price one and it is suppressed. Let Π, the sum of all profits in the economy. I assume that there is no labor-leisure choice, so that income from labor is the value of time sold in the labor market. If the change in the market wage due to the project is “small enough”, I take change in income from labor to be approximately zero. Furthermore, I assume that marginal profit induced by the project is zero elsewhere in the economy.

I therefore write the indirect utility function as;

$$V(p^{dh}, p^{st}, p^{pp}, \Pi, z) \tag{25}$$

V is assumed to have the standard properties of an indirect utility function. Observe that I do not allow for imports of goods to the forestry sector, see Brännlund & Kriström (1997) for this extension.

Consider the program to remove a certain fraction of K^{f} from the market, using the project parameter α. To repeat, this may cause non-marginal price changes in the forestry sector, but only marginal price-changes elsewhere. To obtain a money measure of the welfare change I define compensating variation (CV) as follows;

$$V\left(p^{dh^1}, p^{st^1}, p^{pp^1}, \Pi^1 - CV, z^1\right) = V^0 \tag{26}$$

where V^0 is the welfare in the status quo and the price of the composite good is suppressed. It is important to note that we are evaluating the project at the initial utility level. Thus, the equilibrium prices correspond to compensated demand and supply curves, see Arrow-Hahn (1971). These prices are, in general, not necessarily the same as those would be observe in the markets, since we then consider Marshallian demand and supply curves. It will be convenient to assume that the Marshallian and the Hicksian demand curves are sufficiently similar over the price ranges considered.

Insofar as there are important non-use values attached to the change of forest conservation, the only possible method is a direct method, i.e., by asking individuals about their WTP. This entails presenting a scenario that encapsulates the welfare measure in equation (26), i.e., a counterfactual with new prices and the sum of profits at the new equilibrium. Johansson (1993) shows how the application of a direct method can be simplified. In a way, it allows us to separate the estimation of the benefits and the costs. Johansson (1993) constructs a partial measure CV^p, which in this case will be;

$$V\left(p^{dh^1}, p^{st^1}, p^{pp^1}, \Pi^0 - CV^p, z^1\right) = V^0 \quad (27)$$

Notice that this CV-measure needs considerably less information, since it is to be computed at the benchmark income level. Furthermore, $CV = CV^p + \Delta\Pi$, where $\Delta\Pi = \Pi^1 - \Pi^0$ (the marginal profit change is assumed zero zero in the rest of the economy, given that price is equal to marginal costs in all markets not described here). The respondent is asked about CV^p and the profit changes in the sector are added to get the total value. Finally, note that if income is roughly constant across states of the world, then $CV^p \approx CV$, the usual assumption employed when using a stated preference method. Of course, the question used in the questionnaire will be rather difficult to answer in practice. One would have to detail the consequences for the prices of consumer goods emanating from forestry, explicitly stating that other prices will not change in any material way. At any rate, it will be useful to spell out exactly how the project is supposed to affect the economy, when describing it to the household in the survey.

I now turn to the empirical analysis and begin with the data I used for the costs and the benefits of preservation of forests in Sweden.

9.3 Data

I begin with a broad overview of the data and then turn to details. According to www.skogsindustrierna.se, the Swedish forest industries organization, 115.000 persons are employed in forestry/forest industry. 320,000 or some 3% of the Swedish population are forest owners. 11% of the value of Swedish exports is comprised of forest products (2019). Computations presented in Kriström (2016) using the Balassa index also suggests that Sweden has a comparative advantage in pulp & paper production, in particular. A summary of key data appears in table 1.

Table 1. Forest sector data for Sweden.

Forest-area	$28 \cdot 10^6$ ha (69% of Sweden's landmass)
Gross growth	$115 \cdot 10^6\ m^3$
Fellings	$85 \cdot 10^6\ m^3$
Net stumpage value	$21 \cdot 10^9$ *SEK* (2019)
Value added	$36 \cdot 10^9$ *SEK* (about 8% of value added in industry)

Source: Brännlund (2021)

Value added per hectar is $\frac{36 \cdot 10^9}{28 \cdot 10^6} \approx 1300$ SEK $\cdot\ ha^{(-1)}$, a useful number to keep in mind, given the project studied here. At any rate, these statistics support the idea that the forest sector is important for Sweden's economy. Furthermore, it is widely acknowledged that the forest sector provides substantial non-market values. The non-market benefits generated by Sweden's forests are more difficult to estimate for many reasons, but the idea that they are material is supported by data presented below. I stress that some of the numbers are controversial. For example, net growth of the forest stock results in about 40 mill. ton of CO_2 being sequestered (gross emissions is about 46 mill. ton CO_2-equivalents in Sweden 2020, according to www.scb.se). Carbon locked up in various forest products such as wood furniture are sometimes added suggesting that Sweden's net carbon emission is close to zero. The key controversy regards carbon capture across policies; is a moratorium on cuttings better or worse for the climate compared to intensive forestry? This question is not addressed in this paper, even though a CBA would be of much interest. I now turn to detailed data on the forest sector. I use them to estimate the benefits and costs of the conservation measure that was outlined above.

9.3.1 Market data for the Swedish forest sector

Given the intricate data construction based on Geijer et al (2011), which I will use below, I cite them at length regarding data construction:

> Gross felling destined for sawmills, the pulp industry and the heating industry is used as the supplied (and demanded) quantities. The corresponding prices

> are the average domestic price for sawtimber, pulpwood and wood fuel. Unfortunately, data for the supply of wood fuel has not been collected annually. To fill the gaps, the agency responsible for collecting these data (the Swedish Forest Agency) has chosen to present the same amount over multiple years rather than attempting to approximate the change using other sources of information. This problem is handled in two steps. First, for the last seven years, we approximate the change in the total supply of wood fuel based on the change in wood fuel usage in the heating sector. Secondly, we add a variable for last year's supply of wood fuel to its supply function. The price for both energy and labour in the wood-using industries is calculated implicitly from industry-specific cost and quantities, except for the last years where data concerning wages within different occupations have been used to approximate the wage rate. Since we lack data on the wage rate within forestry, the wage rate from the sawmill industry is used as a proxy. Export prices for (sawn and planed) softwood and wood pulp (sulphate - unbleached) are used as output prices for sawmills and the pulp industry. For the energy industry we have used an implicit output price defined as the ratio between the total revenue from delivered. heating and the delivered quantities. All prices are normalized with respect to the consumer price index. Standing inventory of timber is used as real capital stock for the forest owners. In the demand side real capital to each industry consists of the value of machines and buildings. For the heating sector we have used (one tenth of) the value of the entire energy industry's capital as a proxy for the development of capital in the heating industry. Geijer et al (2011, p. 13)

Regarding their data, the capital stocks (except forestry) is not in real terms. Furthermore, the data on the capital stock in district heating needs to be scaled by a factor of 10. But other than that, I use the data in Geijer et al as is, see table 2.

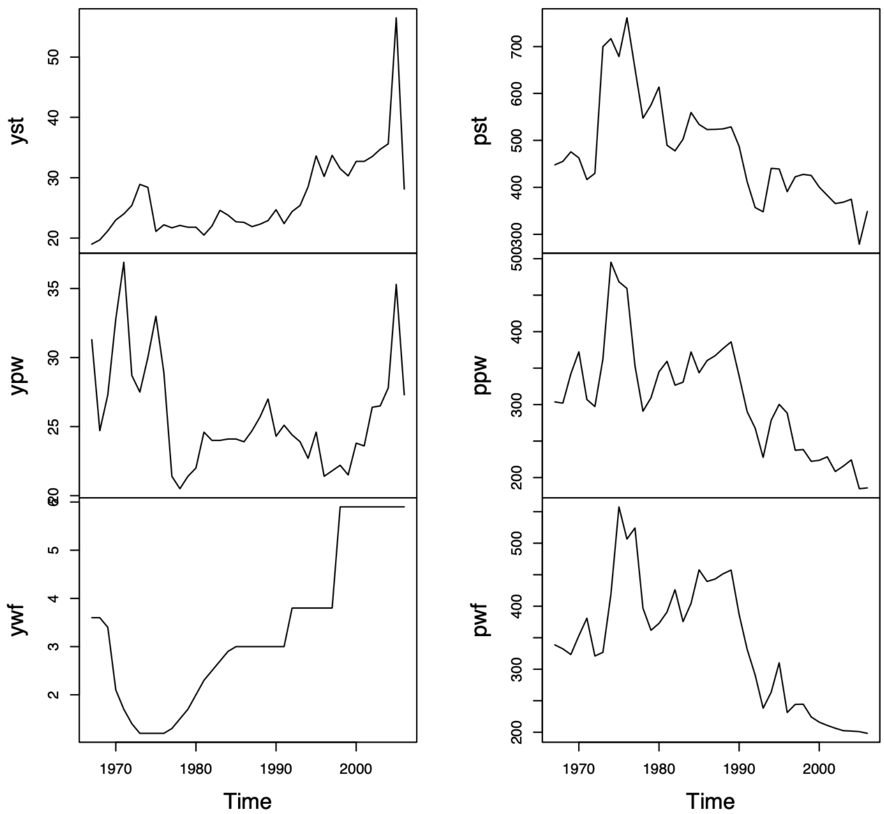
Table 2. Summary statistics of Swedish forest sector 1967-2006

	Mean	sd	Min	Max
Forestry				
y^{st}	26.55	6.80	19.00	56.50
y^{pw}	25.78	3.89	20.50	36.90
y^{fw}	3.36	1.62	1.20	5.90
p^{st}	481.69	110.77	279.11	761.25
p^{pw}	309.81	74.86	184.68	495.12
p^{fw}	339.08	100.19	198.23	557.69
K^{f}	2701.80	269.06	2330.74	3230.00
Sawmills				
p^{sm}	1850.00	273.17	1437.65	2647.44
e^{sm}	41.14	9.32	21.96	54.76
w^{sm}	97.56	9.75	71.96	115.45
K^{sm}	20843.87	5938.30	8326.05	28972.21
Pulpindustry				
p^{pp}	4141.38	918.86	2882.30	6649.35
e^{pp}	25.57	4.89	18.63	38.47
w^{pp}	116.02	14.65	75.77	139.94
K^{pp}	40403.59	9429.93	18892.95	49023.22
District Heating				
p^{dh}	324.17	73.70	211.40	448.52
e^{dh}	107.61	44.21	37.64	211.96
w^{dh}	115.76	14.46	81.66	144.90
K^{dh}	33367.94	10254.68	15688.72	45649.20

Source Geijer et al (2011). Price (e^i, p^i, w^i) data are in 2000 prices using the CPI. Forestry data are in $10^6 m^3$ *and* SEK $\cdot (m^3)^{-}1$, *Sawmills data are in* SEK $\cdot (m^3)^{-}1$, SEK $\cdot (MWh)^{(-1)}$, SEK $\cdot (hour)^{(-1)}$, *and million* SEK, *pulp industry data in* SEK $\cdot (10^3 kg)^{(-1)}$, SEK $\cdot (MWh)^{(-1)}$, SEK$\cdot (hour)^{(-1)}$, *and million* SEK. *Finally heating industry data has units* SEK $\cdot (MWh)^{(-1)}$, SEK$\cdot (MWh)^{-}1$, SEK$\cdot (hour)^{(-1)}$, *and million* SEK

Table 2 provides summary statistics on prices and quantities of the three outputs from the forestry sector. We can see that the fuelwood market constitutes only a very small portion of the yearly cut. Furthermore, the dominant part of what is cut every year is more or less equally divided between pulp- and sawnwood. Figure 1 shows price and quantity over time for the three forestry markets. It is of interest to note that the real price is downward trending, most likely due to productivity gains, whence the volumes are generally up. Notice also the dramatic year 2005, when the storm Gudrun felled roughly a normal year's total cut in two days. 70-75 (estimates vary) mill. m^3 of standing forest became victim of the storm (about 4 years of cut in southern Sweden, where the storm was intense). This natural disaster depressed prices on the forestry markets. The government subsequently imposed price-supports to help the forest-owners to "ride out the storm". Furthermore, as suggested above, the quality of the data on fuelwood is in question, but I have no other data at the moment.

Figure 1. Prices and quantities in the sawlogs, pulpwood and fuelwood markets, 1967-2006, in 2000 prices.



Data from Geijer et al (2011)

Table 3 displays the cross-correlations.

Table 3. Cross-correlations for quantity and price in the forestry markets

	y^{st}	y^{pw}	y^{fw}	p^{st}	p^{pw}	pwf
y^{st}	1.00	0.18	0.64	-0.51	-0.59	-0.67
y^{pw}	0.18	1.00	-0.12	-0.02	0.20	0.10
y^{fw}	0.64	-0.12	1.00	-0.77	-0.81	-0.81
p^{st}	-0.51	-0.02	-0.77	1.00	0.87	0.79
p^{pw}	-0.59	0.20	-0.81	0.87	1.00	0.88
pwf	-0.67	0.10	-0.81	0.79	0.88	1.00

As expected, the supply of the three qualities of wood is positively correlated. This is also expected for the prices. Note, however, that the own-prices for saw-logs and fuelwood are negatively correlated with their own-prices. This is an indication, however weak, that we are identifying the demand function, see Leamer (1981) who gives some conditions on when such an interpretation is valid. Leamer (1981) cites an analysis of Houthakker (1979), in which the latter finds 5 out 59 correlations between output and price to be positive; prices are therefore argued to be more affected by supply than demand. This is intuitively plausible in the application, whence e.g., a pulp-mill is a 24/7 operation that typically runs as long as variable costs are covered, i.e., the own-price demand elasticity is likely to be small (in absolute value). Since I estimate a system of equations, I need not interpret a "quantity versus price regression" in the way that Houthakker suggests.

9.3.2 The ESAB (2018) study

The forest sector analysis by ESAB (2018) is similar to the approach here. While their multi-market model focuses the costs of conservation policy in Sweden, the benefits are assumed constant across their scenarios. The scenario is based on the state-owned company Sveaskog, that swapped 100,000 ha of its forest land to obtain 64,500 ha of preservation-worthy forests owned by forest companies. See Johansson & Kriström (2021) for a conceptual analysis of this program. ESAB (2018) use an updated version of the Geijer et al (2014) model to estimate the market effects. Table 4 presents the estimated price and quantity effects on the markets.

Table 4. Estimated impact on the forestry markets of preserving 64,500 ha old-growth forest in year 2015.

Market	Before	After
Sawtimber quantity	$35.5 \cdot 10^6 m^3$	$35{,}47 \cdot 10^6 m^3$
Sawtimber price	$504 \quad \text{SEK} \cdot (m^3)^{-1}$	$504.2 \quad \text{SEK} \cdot (m^3)^{-1}$
Pulpwood quantity	$30.4 \cdot 10^6 m^3$	$29.3 \cdot 10^6 m^3$
Pulpwood price	$277.1 \quad \text{SEK} \cdot (m^3)^{-1}$	$336 \quad \text{SEK} \cdot (m^3)^{-1}$
Fuelwood quantity	$6 \cdot 10^6 m^3$	$5.98 \cdot 10^6 m^3$
Fuelwood price	$287 \quad \text{SEK} \cdot (m^3)^{-1}$	$290 \quad \text{SEK} \cdot (m^3)^{-1}$

Source: ESAB (2018)

The effects on the sawtimber and fuelwood markets are small. The pulpwood markets are significantly impacted, with a quantity change of almost 1 million m^3 and a 21% price increase. During the years 2015-2018, pulpwood prices increased by 15%, while sawtimber prices remained roughly constant. It is of some interest to note that the model predicts a similar structure of price changes as actually occurred on the market. As noted, the predicted price changes are not unreasonable, given that a pulpmill should be rather price-inelastic in the short-run. It is very costly to shut down operations, not the least compared to sawmills and district heating plants.

9.3.3 Non-market data for the Swedish forest sector

Forest ecosystems provide an array of "ecoservices" that contribute to human well-being, even though such services do not necessarily fetch any market price. For a review of payments for ecosystem services from forests, see e.g. Alix-Garcia & Wolff(2014). A comprehensive review of the concept of ecosystem services is in Gomez-Baggethun (2010). Techniques to value non-market goods have been rapidly developed over the past decades. The portfolio of useful approaches has been expanded, and the strengths and weaknesses of each valuation methods are now better understood, after more than

50 years of applying them. For a non-technical survey of valuation techniques, see e.g., Johansson & Kriström (2018). For a meta-analysis of studies focusing forests ecosystem services using contingent valuation, see e.g., Barrio & Loureiro (2010). A guideline for carrying out such studies in the case of forestry is in Riera et al (2012).

Ideally, the paper would have been built off a valuation survey that mimics the model, but since I do not have such data, I will use some rough approximations. In the calculation, I simply scale down the stock of standing timber, taking no account of the geography. Needless to say, the conservation values will likely depend on precisely which forests that are to be saved. As against that, the political goal regarding forest conservation in Sweden is expressed as a certain number of hectares to be preserved, making no reference to geography (see Johansson & Kriström (2021)).

To obtain the estimate of the value of preserving a fraction of the standing stock of timber in Sweden, consider some studies that have been made on the topic. I will focus on Sweden for natural reasons[5]. It is to be noted that non-market valuation focussing Swedish forests was very active from about the mid 1980s until about 2000, after which there is only a few studies. Indeed, the survey by Lindhjem (2007) on 20 years of valuation research on forest ecosystem services in the Nordic countries is still quite comprehensive.

Hultkrantz (1991) made an attempt to adjust the sectoral forest accounts in Sweden by including several non-priced services provided by forests. To the extent possible, Hultkrantz (1991) utilizes market prices to evaluate each component. Market data is available for timber, berries and mushrooms. The value of meat from hunting and recreational values are obtained from a contingent valuation study. Biodiversity is valued by considering the area of protected land that must be set aside to protect biological diversity. Hydrological effects, e.g., forest absorption of water that could have been used for power generation, are not valued explicitly. Carbon fixing is valued by using the effluent fee of carbon dioxide. Note that Hultkrantz (1991) counts the increase of growing forest stock twice. First, the timber value and then the value of carbon fixing. The annual depletion of exchangeable cations in forest soils can be compensated by liming, and this cost is used as a proxy. For lack of data, nitrogen

[5] There are many similar studies from other countries, see e.g., Campos & Caparrós (2006) for an application to Spain

leaking is not considered explicitly. Forests (in the North of Sweden) also provide reindeer forage. Because changes in lichen stocks are not included in the current accounts, Hultkrantz (1991) utilizes studies on opportunity costs to obtain a value of the change in stocks. Note that the consumption of reindeer forage is already included in the national accounts, because the availability of reindeer forage will affect profits in this industry. Hultkrantz (1991) obtains a "green" NNP for the Swedish forest sector; the ecosystem services add roughly 20% to the value of forestry output. This is an indication, however weak, that the market values may be larger than the non-market ones. Updates of Hultkrantz(1991) are available in Eliasson (1995) and Kriström & Skånberg (2001) with similar results.

While there are a few studies of green accounting using national data, there are now a large number of studies of non-market forest benefits that uses household data. A significant number of studies focus on the recreational value of forests. Bojö (1985) applied both the travel cost method and the contingent valuation method to estimate the environmental benefits from the preservation of a forest area in the Vålå Valley in Northern Sweden. Both valuation methods indicated that a preservation alternative was preferable. The area was subsequently protected from forest harvesting. Kriström (1990) asked a sample of 1100 Swedish households about their WTP for the preservation of 11 pristine (old-growth) woodlands in Sweden. A lower bound estimate of the aggregate WTP for all Swedish households was found to be *SEK* 3.8 billion (*SEK* 1 ≈ USD 1/11 in 2022). This was compared to the value of a cutting alternative, suggesting that the benefits of preservation may outweigh the costs for the areas under study. Mattson & Li (1993) used the contingent valuation method to study non-timber values in the county of Västerbotten in northern Sweden. They attempted to quantify the non-timber value from on-site consumptive use (berry- and mushroom-picking), on-site non-consumptive use (hiking, camping, etc.), and off-site visual experience. Perhaps the study that comes closest to the project envisioned here, is Broberg's (2007) about Swede's WTP for preserving old-growth forests in North-West of Sweden. His scenario is similar to a proposal made in a remit (SOU 2020:73) of preserving 500 000 ha of forests in the north-west. He uses CVM and reports a total value of 9 billion *SEK* for the preservation program.

There are a number of databases that collate valuation studies. ValuebaseSWE for Sweden (Kinell et al (2009)) and its aggregate, e.g. the Nordic valuation studies database (http://norden.diva-portal.org/smash/get/diva2:700735/FULLTEXT01.pdf) and global EVRI database (www.evri.ca). The report by Kinell et al (2009) derives estimates about the value of preservation of forests. It is difficult to convert these estimates to something that can be compared to the cost of taking away a percentage of the standing stock of timber. One reason is that the object of valuation differs substantially between the different studies. At any rate, at the individual level, the lower bound is 2372 *SEK* as a one-time payment to 5 685 *SEK* per year, the latter being converted to an aggregate estimate of about 1 billion per year (Mattsson & Li (1993)), although this number pertains only to a fraction of Swedish forest land.

Brännlund et al (2015) provide a CBA of “Intensive cultivation” compared to “conventional” forest use in Sweden, accounting for various non-market goods. Intensive cultivation are productivity-enhancing measures within forestry, such as reforestation of agricultural lands, increased use of fertilizer and proactive measures that limit damage to seedlings by moose and other wild game. The authors include carbon sequestration, acidification and nutrient loading, landscape changes and recreational value (including hunting) among the non-market goods, but not biodiversity. The market effects of more intensive forest management include larger harvests, as well as increased use of bioenergy that substitutes away from fossile fuels.

According to the remit to the government carried out by the Swedish University of Agricultural Sciences (ESAB (2018)) mentioned above, non-market values appreciated by a forest owner amounts to 350 $\text{SEK} \cdot ha^{-1} \cdot year^{-1}$. This value is based on literature surveys and numerical analysis undertaken by the remit. Whether or not this can be taken to be a reasonable approximation of a non-owner’s valuation is not clear.

The most recent data has been collated by Brännlund (2021). He considered the benefits and costs of “shutting down” forestry operations in Sweden. The value of biodiversity is not estimated, given the measurement difficulties. Tourism values are assumed not to be much affected, given that Sweden already has a number of national parks and otherwise protected forests. Recreation is also not necessarily only negatively affected by forestry, whence forestry activities have allowed access to many remote areas by the construction of roads. Since more than 90% of the Swedish population visits a forest every year in present conditions [6], it seems reasonable to assume that there is a recreation value even when forestry is operative. Furthermore, certain berries are affected positively by clear-cuttings. Finally, moose-hunting, a traditionally very popular type of hunting in Sweden, has actually benefited from forestry, whence the stock of moose has increased, most likely via increased forestry. Consequently, there are several difficulties involved when trying to find a good estimate of the benefits of preservation. The contingent valuation study carried out by Kriström (1990) included a scenario that effectively proposed to save some 700000 hectares of old-growth forest. The willingness-to-pay (EV) was found to be 1000-3000 SEK per person as a lumpsum, depending on the estimation method. This is approximately 0.001-0.004 SEK per ha and person. Multiplying by the number of inhabitants in Sweden ($10 million$) today I obtain about 29000 SEK per ha using the midpoint. Converting to a yearly payment using a discount factor of 5%, I get 1450 SEK per ha. This value includes use and non-use values. The uncertainty is, of course, huge, but the results are comparable to Brännlund (2021).

Table 5 summarizes the above discussion about benefit estimations.

Table 5. Selected studies of conservation non-market values

Study	Non-market value	Good
Kriström (1990)	3.8 billion SEK	conserving 700 000 ha (EV)
Hultkrantz (1991)	20% of value added	Ecosystem services. Green national accounts for forestry
Mattsson & Li (1993)	50% of production value	Forest recreation, County of Vasterbotten
NiER (1999)	20 billion $\mathrm{SEK} \cdot yr^{(-1)}$	Forest recreation, Sweden
Broberg (2007)	9 Billion SEK	Preservation of old-growth forest in Northwestern Sweden

[6] See https://www.slu.se/globalassets/ew/ew-centrala/forskn/popvet-dok/faktaskog/faktaskog96/fs1996018.pdf

9.4 The Econometric model

The objective next is to estimate demand and supply curves in the forest sector. There are several useful functional forms, here we want to cater for multioutput technologies and quasi-fixed inputs. Behrman et al (1992) proposed a CET-CES-GL profit function, which refers to the constant elasticity of transformation and constant elasticity of substitution between pairs of outputs and inputs. I will use a special case of this function; an augmented Generalized Leontief (GL) to cater for quasi-fixed capital inputs, following Diewert (1973), see also Bergman (1995). Standard properties of a profit function include homogenenity of degree one in prices, I will also require that it is homogenous of degree one in $K^s \forall s \in \mathtt{f,nf}$ see Diewert (1973). This implies constant returns to scale in all factors, see Bergman & Brännlund (1995) for extensions to the non-homogenous case.

For estimation purposes, I divide each equation by the capital stock, to obtain:

$$\begin{aligned}
\frac{y^{fw}}{K^{\mathrm{f}}} &= \beta_{11} + \beta_{12} \cdot \sqrt{\frac{p^{pw}}{p^{fw}}} + \beta_{13} \cdot \sqrt{\frac{p^{st}}{p^{fw}}} + \beta_{14} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{fw}}} \\
\frac{y^{pw}}{K^{\mathrm{f}}} &= \beta_{22} + \beta_{21} \cdot \sqrt{\frac{p^{fw}}{p^{pw}}} + \beta_{23} \cdot \sqrt{\frac{p^{st}}{p^{pw}}} + \beta_{24} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{pw}}} \\
\frac{y^{st}}{K^{\mathrm{f}}} &= \beta_{33} + \beta_{31} \cdot \sqrt{\frac{p^{fw}}{p^{st}}} + \beta_{32} \cdot \sqrt{\frac{p^{pw}}{p^{st}}} + \beta_{34} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{st}}}
\end{aligned}$$

For the demand of forestry products I obtain

$$\begin{aligned}
\frac{x^{fw}}{K^{\mathrm{dh}}} &= -\left(b_{11} + b_{12} \cdot \sqrt{\frac{\overline{p^{dh}}}{p^{fw}}} + b_{13} \cdot \sqrt{\frac{\overline{e^{df}}}{p^{fw}}} + b_{14} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{fw}}} \right) \\
\frac{x^{pw}}{K^{\mathrm{pp}}} &= -\left(b_{22} + b_{21} \cdot \sqrt{\frac{\overline{p^{pp}}}{p^{pw}}} + b_{23} \cdot \sqrt{\frac{\overline{e^{pp}}}{p^{pw}}} + b_{24} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{pw}}} \right) \\
\frac{x^{st}}{K^{\mathrm{sm}}} &= -\left(b_{33} + b_{31} \cdot \sqrt{\frac{\overline{p^{ps}}}{p^{st}}} + b_{32} \cdot \sqrt{\frac{\overline{e^{st}}}{p^{st}}} + b_{34} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{st}}} \right)
\end{aligned}$$

Symmetry requires that the mixed partials of the profit functions are identical, which implies the parameter restrictions $a_{ij} = a_{ji}, i \neq j$, where a is a parameter of the supply equations, and the same for the demand equations, referring to the mixed partial of each profit function in the model.

Estimation results

Due to lack of data, wages in sawmills are used as an approximation of wages in forestry. I include a dummy-variable for the storm Gudrun in 2005. The estimation results are on the whole disheartening, whence the data refuses to fit the theory. Among other things, we find negatively sloped supply curves and other violations of the basic assumptions. Therefore, I am going to use the Geijer et al (2011) model, that is not as tightly linked to theory as the preferred one here. This means that the welfare measures do not have a straightforward interpretation, so they will have to be considered as simply illustrative of the basic idea. Better data and further exploration of suitable econometric models are useful future research tasks to develop this methodology.

Geijer et al (2011) use an econometric model very similar to that proposed here. The essential difference is that they add the capital stock linearly and add some other exogenous variables. Their approach can be considered an approximation of the GL-strategy employed here, in which we made a point of including the capital stocks in a formally correct manner. For ease of comparison, I use their notation for the parameters. Their econometric specification can be written as

$$y_t^i = \sum_j \alpha_{ij} \sqrt{\frac{p_t^j}{p_t^i}} + \alpha_i \cdot t, \quad \{i = fw, pw, st\}, \{j = fw, pw, st, w_f^l\} \tag{34}$$

$$-x^{fw} = \sum_j \delta_j \sqrt{\frac{p_t^j}{p_t^{fw}}} + \delta_k \cdot K_t^{dh} + \delta_{x-1} \cdot x_{t-1}^{fw}, \quad \{j = dh, fw, pw, w_{dh}^l\} \tag{35}$$

$$-x^{pw} = -\sum_j \lambda_j \cdot \sqrt{\frac{p_t^j}{p_t^{pw}}} + \lambda_k \cdot K_t^{pp} + \lambda_{x-1} \cdot x_{t-1}^{fw} + \lambda_t \cdot t, \quad \{j = dh, w_{pp}^l, e^{pp}\} \tag{36}$$

$$-x^{st} = -\sum_j \beta_j \sqrt{\frac{p_t^j}{p_t^{st}}} + \beta_k \cdot K_t^{sm} + \beta_{x-1} \cdot x_{t-1}^{st} + \beta_t \cdot t, \quad \{j = ps, st, w_{sm}^l\} \tag{37}$$

Thus, there are additional variables, e.g., lagged dependent variables that are difficult to align with the standard theory. It can be integrated, but not with the theory used here. But this set-up can be considered a rough approximation of the underlying technologies, even though I prefer my first set-up. Be that as it may, the estimation results are lifted from the Geijer et al (2020) paper and reproduced in Figure 2. The parameters are estimated with three stage least squares (3SLS), where all the exogenous variables are used as instruments. Furthermore, Prior to estimating the system, a dummy variable for the 2005 storm “Gudrun” were added to the supply functions. A dummy for the first oil crisis (1973-1974) in the supply function for wood fuel, and a dummy for the Swedish financial crisis (1992-1994) was added to the demand function for forest fuel. Symmetry in the supply functions of forestry products was imposed, by requiring that $a\alpha_{ij} = \alpha_{ij}$. Variance and standard errors were computed by White’s heteroscedasticity corrected standard errors.

Figure 2. Reproduction of the estimation results in Geijer et al (2011)

Sawtimber			Pulpwood			Wood fuel		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
α_{ss}	74.82	519.53	α_{pp}	1753.9	511.7*	α_{wh}	21.00	7.20*
α_{sp}	-1.02	5.09	α_{ps}	-1.02	5.09	α_{ws}	-20.0	4.00*
α_{sw}	-20.0	4.00*	α_{pw}	-1.84	3.55	α_{wp}	-1.84	3.55
α_{sl}	-5.00	20.06	α_{pl}	-5.95	14.58	α_{wl}	29.32	8.47*
α_{sk}	0.015	0.014	α_{pk}	0.037	0.013*	α_{wk}	-.37E-2	0.002*
α_{st}	-0.035	0.278	α_{pt}	-0.92	0.27*	$\alpha_{y\text{-}1}$	0.99	0.16*
α_{sG}	23.11	1.83*	α_{pG}	7.81	1.35*	α_{wG}	-4.78	0.96*
						α_{wOC}	3.92	0.93*
$R^2 = 0.88$			$R^2 = 0.45$			$R^2 = 0.75$		

Sawmills			Pulp Industry			Heating Industry		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
β_{st}	-179.0	635.0	γ_{pw}	333.5	376.0	δ_{wf}	1.74	0.85*
β_{s}	-10.0	7.87	γ_{p}	-2.90	1.10*	δ_{h}	-1.17	1.17
β_{se}	100.3.	31.9*	γ_{pe}	-14.5	16.6	δ_{hf}	-0.32	0.86
β_{sl}	-98.85	41.60*	γ_{pl}	13.9	17.4	δ_{hl}	-1.29	1.39
β_{k}	.37E-3	.31E-3	γ_{k}	.30E-3	.12E-3*	δ_{k}	-.92E-5	.86E-5
$\beta_{x\text{-}1}$	-0.05	0.13	$\gamma_{x\text{-}1}$	-0.19	0.07*	$\delta_{x\text{-}1}$	-0.85	0.14*
β_{t}	0.09	0.33	γ_{t}	-0.18	0.19	δ_{hV}	0.13	0.33
$R^2 = 0.66$			$R^2 = 0.48$			$R^2 = 0.95$		

Observe that the demand parameters have a negative sign in front of them, given the way the equation system is set-up. Overall, about 50% of the parameters are significant. Geijer et al (2010, p. 17) observes that:

> Capital appears to be a substitute for wood input in both the sawmills and the pulp industry, but is a complement in the heating industry. According to the estimates, the storm Gudrun caused a rather big increase in the supply of saw timber and pulpwood, but decreased the supply of wood fuel. This seemingly

strange result for the wood fuel supply might partly be explained by the high average temperature during 2005, which might have decreased the overall need for heating and thus demand for all types of primary energy.

I am going to use the parameters to evaluate the reform discussed above. Again, these computations are made only to illustrate a possible approach to CBA in multimarket equilibrium models, it is not an attempt to evaluate Swedish policy per se.

9.5 Cost-benefit analysis

For the purpose of comparison with the Government proposal, we use numbers in Kriström (1990), see also Broberg (2007). One of the areas considered in Kriström's (1990) analysis for conservation is in the north-west of Sweden and coincides fairly closely with the government proposal. It contains, according to his estimate 574400 ha (Kriström (1990, p. 114)), with a forest content in the range 73-85 $m^3 ha^{-1}$. Given the rather difficult terrain, with a significant share of low-productive land, a fairly low net conversion value of 70 $SEKm^{-3}$ was used. The opportunity cost in Kriström's (1990) timber mining alternative was estimated to be 2.9-3.4 10^9 SEK in 1990 prices. These estimates are thus based on the assumption that the project is marginal. A very rough estimate would then be $\frac{5.744}{7}(2.9-3.4) = 2.4 - 2.8$ billion SEK for the government proposal (in 1990 prices). Geijer et al (2011) considers a slightly larger conservation project, amounting to setting aside 3% of the forest capital stock, calibrating to the year 2000. The find a total loss of roundwood in total at about 5.37 million m^3 in the short-run, but do not compute the change in profits in the sector. Valuing their (short-run result) by share-weighted prices, an upper-bound estimate since it ignores the opportunity costs, the total value is about 1.7 billion SEK in 2000 prices, which is about 1.35 billion SEK in 1990 prices [7]. This estimate is also on the assumption of "timber-mining", as if the forest would be a non-renewable resource. As in the Geijer et al (2011) paper, I am going to use the situation in the year 2000, as a starting point for my simulation. When computing the elasticities (which values depend on the data), they use average values on observed data 2000-2004, which could partly explain any

[7] Using CPI and https://www.scb.se/hitta-statistik/sverige-i-siffror/prisomraknaren/

differences between this my result and theirs. At any rate, the parameters for my simulation is in table 6.

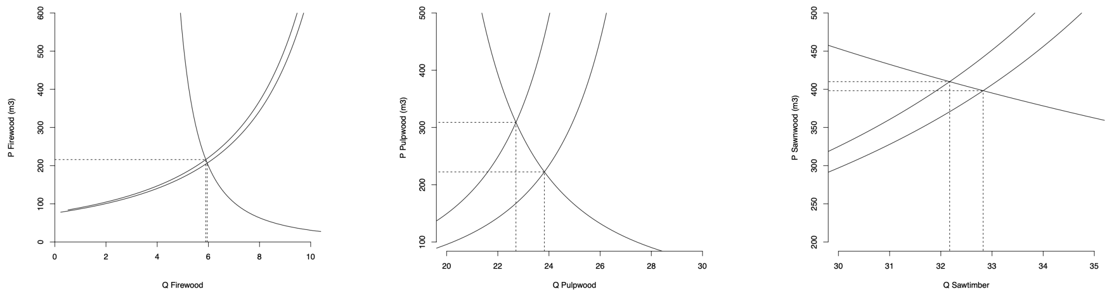
Table 6. Parameter values for the simulation.

(For units, see table 2)

	parameter	value
1	year	2000
2	y^{st}	32.7
3	y^{pw}	23.8
4	y^{fw}	5.9
5	p^{st}	400.5
6	p^{pw}	223.7
7	p^{fw}	216
8	w^{f}	102.3
9	K^{f}	3008
10	p^{sm}	1622
11	e^{sm}	25.2
12	l^{sm}	102.3
13	K^{sm}	27464.4
14	p^{pp}	4640
15	e^{pp}	20.1
16	w^{pp}	120.5
17	K^{pp}	48997.4
18	p^{dh}	344.7
19	e^{dh}	107.5
20	w^{dh}	130.9
21	K^{dh}	4403

Calibrating to the year 2000, we can perturb the multimarket equilibrium by setting $\alpha = 0.98$, i.e., removing 2% of the standing stock of timber K^f. The consequences on the roundwood markets for the chosen path of integration is displayed in figure 3.

Figure 3. Roundwood market consequences of conserving 2% of the Swedish standing stock of timber on productive forest lands, for the path $\{\mathbf{p^{fw}} \rightarrow \mathbf{p^{pw}} \rightarrow \mathbf{p^{st}}\}$



Observe that we compute the equilibria sequentially, arbitrarily beginning with the fuelwood market and then computing the equilibrium in the pulpwood market, conditional on the new price of firewood. Lastly, we compute the equilibrium in the sawtimber market, given the other two new equilibrium prices.

An integral is path-independent, if the value of the path-integral is independent of the chosen path. In this case, if we compute the sum of the profit changes, we must do that for some chosen path in $\Re^3$, since we have assumed that other prices remain constant. It remains to be shown in this particular case, that the sum of consumer and producer surplus is independent of the chosen path. I will proceed in a simpler way, given the limited objective of this exercise. Thus, in each market we compute the sum of consumer and producer surplus, using a linear approximation $dp^i \cdot dy^i, i \in \{fw, pw, st\}$, essentially a version of the rule-of-one-half (we sum two triangles rather than one and assume symmetry). The result of the simulation is

Table 7. Profit, quantity and value of quantity changes valued at the new equilibrium using linear approximation of the relevant areas, for the path $\{\mathbf{p^{fw}} \to \mathbf{p^{pw}} \to \mathbf{p^{st}}\}$

$\Delta\Pi^{fw}$	-0.52
$\Delta\Pi^{pw}$	-96.39
$\Delta\Pi^{st}$	-6.74
$\sum\Delta\Pi$	-103.65
$\sum\Delta y$	-1.78
Δy^{fw}	0.06
Δy^{pw}	-1.13
Δy^{st}	-0.70
$p^{fw} \cdot \Delta y^{fw}$	11.44
$p^{pw}\dot{\Delta} y^{pw}$	-349.34
$p^{st}\dot{\Delta} y^{st}$	-289.03

From the point of view of society, I estimate that about 1.78 million m^3 less is sold at the three roundwood markets. Overall, the structure of the results is similar to Geijer et al (2011), although for this illustration I obtain a different result on the firewood market. The data on firewood is notoriously of bad quality, but since it is such a small portion of the roundwood markets it will not matter much for the overall results. For the chosen path, my results are generally lower than what Geijer et al (2011). They do look at a more significant change (900,000 ha withdrawn, rather than about 500,000 here), but there is still a larger difference than what I expected. What is more, as Geijer (2010) and ESAB (2018), among others, have noted, the main effect will be seen at the pulpwood market. The industry is price-inelastic and have few alternatives to simply running their factories in the short-run. In my illustrative simulation, the larger quantitative effect is rather on the pulpwood market.

I will abstain from making any comment on whether the proposed government policy is socially profitable, whence it has not been my aim to address this question. It is still of some interest to note that the benefits and the costs are in the same ballpark, which perhaps is one explanation why the conflicts about the husbandry of our forests remains a topic for intense discussion.

9.6 Conclusion

When both income and an externality is changing with a project, welfare evaluation becomes more difficult. In such cases, it might be of interest to consider the multimarket equilibrium approach. I argue here that Johansson's (1993) separation result can be used within this setting, although his result is derived within a full general equilibrium setting. I necessarily then have to make stringent assumption about e.g., price changes outside of the sector under scrutiny. It would seem that there are cases when a particular sector is of focal interest for policy analysis. Consider, for example, the planned windpower expansion in many countries. Expansion of windpower might well have effects that are limited to a small number of markets. In addition, such expansion do have an impact on the environment. Perhaps the suggested approach can have merit in this case. Alternatively, one might consider a CGE-approach, if the project is "large enough" – the electrification of economies in the EU might be a case in point. My view is that project analysis should begin with the "small project" assumption and be based on received welfare measurement in general equilibrium. In many cases, this will be a useful starting point. There are cases, such as the one studied in this paper, when a multi-market analysis seems natural. But overall, it is useful to have a broad toolkit when doing project analysis, and multi-market welfare measurement is, I would argue, one useful tool in this endeavour.

References

Alix-Garcia, J., & H. Wolff. (2014). "Payment for Ecosystem Services from Forests." Annual Review of Resource Economics 6 (1): 361–80. https://doi.org/10.1146/annurev-resource-100913-012524.

Alston, J.M., & J. S. James (2002). "The incidence of agricultural policy". *Handbook of agricultural economics* 2: 1689–1749.

Ankarhem, M. (2005). "Effects of increased demand for biofuels: a dynamic model of the Swedish forest sector". Mimeo, Umeå university.

Arrow, K.J. & F. Hahn (1971). *General competitive analysis*, North-Holland, Amsterdam.

Bailey, M. J. (1964). "The Marshallian Demand Curve". *Journal of Political Economy*, 62, nr 3, 255–61. https://doi.org/10.1086/257518.

Barrio, M., & M. L. Loureiro. (2010). "A Meta-Analysis of Contingent Valuation Forest Studies." Ecological Economics 69 (5): 1023–30. https://doi.org/10.1016/j.ecolecon.2009.11.016.

Bergman, M. A. (1997). "The Restricted Profit Function and the Application of the Generalised Leontief and the Translog Functional Forms." International Journal of Production Economics 49 (3): 249–54. https://doi.org/10.1016/S0925-5273(97)00011-X.

Broberg, T. (2007). The value of preserving nature: Preference uncertainty and distributional effects, Diss. Department of Economics, Umeå University.

Brännlund, R., O. Carlén, T. Lundgren, & P.-O. Marklund. (2012). "The Costs and Benefits of Intensive Forest Management." Journal of Benefit-Cost Analysis 3 (4): 1–23. https://doi.org/10.1515/2152-2812.1105.

Bojö, J. (1985). Kostnadsnyttoanalys Av Fjällnära Skogar: Fallet Vålådalen. Research Report Ekonomiska Forskningsinstitutet Vid Handelshögskolan i Stockholm 205. Stockholm.

Brännlund, R., & B. Kriström (1996). “Welfare measurement in single and multimarket models: theory and application”. *American Journal of Agricultural Economics*, 1996. *http://www.jstor.org/stable/1243787*.

Brännlund, R., & B. Kriström. (1997). “Taxing Pollution in an Open Economy an Illustration from the Nordic Pulp Industry”. *Journal of Forest Economics*, 3, 189-205.

Campos, P., & A. Caparrós. (2006). “Social and Private Total Hicksian Incomes of Multiple Use Forests in Spain.” Ecological Economics 57 (4): 545–57.

Carbone, J. C., & V. K. Smith. (2013). “Valuing nature in a general equilibrium”. *Journal of Environmental Economics and Management* 66: 72–89.

Chetty, R. (2009. “Sufficient Statistics for Welfare Analysis: A Bridge Between Structural and Reduced-Form Methods”. *Annual Review of Economics* 1, nr 1 (September 2009): 451–88.
https://doi.org/10.1146/annurev.economics.050708.142910.

Eliasson, P. (1996). “Evaluation of carbon fixation in the context of national accounts.” Arbetsrapport 231. Institutionen för skogsekonomi, Lantbruks Universitet, Sweden.

ESAB (2018). “samhällsekonomisk konsekvensanalys av metoden för att skydda värdefulla skogar inom Ersättningsmark i Sverige AB”, Faculty of Forestry, SLU, Umeå, ua 2018.2.6-272.

Feldstein, M. (1999). “Tax Avoidance And The Deadweight Loss Of The Income Tax”. *The Review of Economics and Statistics* 81, nr 4, : 674–80.

Geijer, E., Bostedt,G. & R.Brännlund (2011). “Damned If You Do, Damned If You Do Not—Reduced Climate Impact vs. Sustainable Forests in Sweden”. *Resource and Energy Economics* 33, nr 1: 94–106. *https://doi.org/10.1016/j.reseneeco.2010.01.004*.

Gomez-Baggethun, E., de Groot, R., Lomas, P. L. & C. Montes. (2010). “The History of Ecosystem Services in Economic Theory and Practice: From Early Notions to Markets and Payment Schemes.” *Ecological Economics*, 69 (6): 1209–18. https://doi.org/10.1016/j.ecolecon.2009.11.007.

Harberger, A.C. (1964). “The Measurement of Waste”. *The American Economic Review* 54, nr 3,: 58–76.

Johansson, P.-O. (1993). *Cost-benefit analysis of environmental change*. Cambridge ; New York: Cambridge University Press.

Johansson, P.-O., & B. Kriström. (2016). *Cost-Benefit Analysis for Project Appraisal*. Cambridge: Cambridge University Press. http://ebooks.cambridge.org/ref/id/CBO9781316392751.

Johansson, P-O, och B Kriström. (2018). *Cost-Benefit Analysis*. Cambridge Elements. Cambridge, UK: Cambridge University Press.

Just, R.E., D.L. Hueth, & A. Schmitz. The Welfare Economics of Public Policy: A Practical Approach to Project and Policy Evaluation. Edward Elgar Publishing, Incorporated, 2005. https://books.google.se/books?id=GXwAAgAAQBAJ.

Kinell, G., Söderqvist, T. & L. Hasselström (2009). "Monetära schablonvärden för miljöförändringar", Rapport 6322, Naturvårdsverket.

Kriström, B. (1990). Valuing Environmental Benefits Using the Contingent Valuation Method: An Econometric Analysis. Umeå Economic Studies. University of Umeå. http://books.google.se/books?id=hu0sAQAAMAAJ.

Kriström, B. & K. Skånberg (2001). "Monetary forestry accounting including environmental goods and services." Forest Sys;10(3):7-26. Available from: https://revistas.inia.es/index.php/fs/article/view/731.

Lindhjem, H. (2007). "20 Years of Stated Preference Valuation of Non-Timber Benefits from Fennoscandian Forests: A Meta-Analysis." Journal of Forest Economics 12 (4): 251–77. https://doi.org/10.1016/j.jfe.2006.09.003.

Mattsson, L,. & C-Z Li. (1993). "The Non-timber Value of Northern Swedish Forests: An Economic Analysis." Scandinavian Journal of Forest Research 8 (1–4): 426–34. https://doi.org/10.1080/02827589309382789.

Riera, P., Signorello, G., Mara, T, Mahieu,P-. A., Navrud, S. Kaval,P., Rulleau, B. et al. (2012). "Non-Market Valuaetion of Forest Goods and Services: Good Practice Guidelines." Journal of Forest Economics 18 (4): 259–70. https://doi.org/10.1016/j.jfe.2012.07.001.

SOU (2020:73). “Stärkt äganderätt, flexibla skyddsformer och naturvård i skogen”, Remit, Ministry of Environment, https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2020/11/sou-202073/