
MIKAIL LINDEN¹ and JUSSI LEPPÄNEN²

¹Department of Business and Economics, University of Joensuu, Yliopistokatu 7, P.O. Box 111, FI-80101 Joensuu, Finland, and ²Finnish Forest Research Institute, Unioninkatu 40 A, FI-00170 Helsinki, Finland

INTRODUCTION

Public intervention in forestry has traditionally been implemented by introducing macroeconomic planning for the forestry sector to achieve social benefits. Before public intervention, various forest management practices usually prevail, especially in forests owned by non-industrial private forest (NIPF) owners. Industrialized nations have shown a tendency towards increasing wood consumption, which gives forest industries an incentive to over-cut. Therefore, in many countries public interventions have been carried out to sustain round wood stocks through forestry planning systems and management intensification (Ellefson 1992). Basically, these measures have been implemented by adopting an even-age management regimen for forests.

In Finland, the framework of public intervention in non-industrial private forestry was created during the twentieth century, initially with legislation, and since 1928 with extension and funding for selected forestry activities. A major change in forestry policy took place during the 1960s, with increased public intervention in forest management and financing. This was carried out via several large-scale forestry programmes and additional budget expenditures. The aim was to increase the long-term cutting potential of the forests (see Uusitalo 1978, Palosuo 1979). In the 1950s, cuttings were already exceeding annual growth, and the sustainable cutting budget was of increasing concern to public decision makers. After the success experienced with the post-war industrial policy, challenges emerged for a new supply side policy in forestry. Forestry intensification was also seen as a source of increased social welfare and as a part of regional policy. In the Finnish case, the basis for the new forest policy was the expected increase in forest industry investments and, consequently, in commercial fellings. In addition, the mechanization of forestry operations increased at this time and new management regimens were needed.

In practice, forestry intensification was achieved by increasing the share of clear-cutttings in final fellings. This led to an expansion of artificial regeneration and a consequent need for tending seedling and young stands. In addition, many peatlands were drained, fertilization was increased and a dense network of forest roads was built. All these measures were made feasible by directions and substantial financial assistance from government. The change in forest policy was implemented by the Forest Financing Pro-
grammes (MERA) during the period 1965–1975, and these forestry programmes had successors well into the 1980s. It was not until the 1990s that the policy aiming at intensive forestry was called into question in Finland. During the 1990s, changes in environmental and social values began to affect many forestry routines. In 1999, Finland’s National Forest Programme 2010 (FNFP) was introduced to bring forestry practices into accord with economic, environmental and social values. The FNFP incorporated environmental impacts assessment in which, among other things, the lack of *ex ante* evaluations of financial assistance for forestry was subjected to criticism. In addition, an FNFP working group has introduced the need for forest protection and environmental forest management to take endangered species into account (Ministry of the Environment, 2000).

Despite the economic measures taken to increase roundwood inventories (see e.g. Kuusela & Salminen 1991), there have been very few *ex post* evaluations of the costs and benefits of the large-scale public sector aid and investments in NIPF. The direct costs consist of support for forestry extension organizations and funding of NIPF investments and special forestry programmes. The macroeconomic monetary benefits, consisting of direct and indirect economic effects, have been discussed by Juurola et al. (1999). Note that many different forest policy means also affect private forest investments. High commercial interest rates, reforestation and thinning mandatory are good examples. However, these aspects are not so important in this context since financial support (aid, grants and loans) to NIPF in Finland is targeted to cover the private expenses of different programmes and regulations.

The general economic effects of public aid on forest investments were analysed, both theoretically and empirically, by Linden & Leppänen (2003). Using regional data from the period 1983–2000 they showed that public aid has had clear positive investment incentive effects among Finnish NIPF owners. However, this analysis did not address the issues of complementarity and substitution that arise in the relationship between private forest investments and public cost-sharing of these investments. The question is important because if public aid results in complementarity when keeping other things fixed, policy has been beneficial since it increases private forest investments.

This study analysed, first, the effects of public cost-sharing on private forest investment with a simple cost-sharing optimization model. Theory implications favour the substitution case. Next, the translog cost function approach was used to model empirically the complementarity and substitution effects in three different forest investment classes: private investments with no public support; private, individual investments with public support; and private, collective investments with public support. The third class consists of projects in which several NIPF owners participate at the same time (e.g. building of forest roads and ditches). The translog cost function approach entails that the cost shares of these three investments classes are modelled simultaneously. The explanatory variables consist of unit cost prices and volumes of investments. The approach is well suited for testing the different economic hypotheses concerning (1) complementarity and substitution among investment categories, (2) investment scale effects, and (3) symmetry restrictions derived from economic theory. The empirical analysis was conducted with yearly aggregate observations from the period 1963–2000 among Finnish NIPF owners.

**MATERIALS AND METHODS**

**A model of cost sharing**

Since the forest investment are costly and slowly maturing, the socially optimal level of investments is not warranted. The private incentive for forest investments may be low for many reasons. The relative low return of forest capital makes alternative investment projects more attractive than wood production. Self-financed investments reduce current consumption. The long maturity of forest investments and risks involved therein are difficult to reduce. To sustain the socially optimal level of wood supply, the government must finance the private forest owners to keep their forest investments at the desired level. Grants, loans with interest rates below market rates and tax concessions are the parts of this cost-sharing policy with respective technical assistance. In general, the incentive structure has been one wherein, once the private forest owner starts his forest investment project, the government will support and partly cover the financial costs.

Assume that the representative private forest owner faces a following decision problem. He has to choose the level of private funding $R$ to provide desired level
of investment capital $I$ at given price level $q$. Assume that capital is the only input in his concave forest output function ($f_I > 0$, $f_{II} < 0$). He is also allowed public financial aid up until fraction $\bar{\alpha}$ of $R$. The maximization problem is:

$$\max_{R, \bar{\alpha}} f(I) - C(R)$$

subject to $qI = (1 + \bar{\alpha})R$ and $\bar{\alpha} \leq \alpha < 1$ (1)

$C(R)$ is a convex cost function of private investment funds ($C_R > 0$, $C_{RR} > 0$). The Lagrangian of the problem is:

$$L(R, \bar{\alpha}) = f([(1 + \bar{\alpha})R]/q) - C(R) - \lambda[q - \bar{\alpha}]$$ (2)

The first order conditions are:

$$\begin{cases} 
\partial L/\partial R = \frac{1 + \bar{\alpha}}{q} f_I - C_R = 0 \\
\partial L/\partial \bar{\alpha} = \frac{R}{q} f_I - \lambda = 0
\end{cases}$$ (3)

The forest investments increase because public aid allows for marginally more expensive forest capital investments: $C_R = (1 + \bar{\alpha})f_I/q > f_I/q$. The forest owner uses all cost-sharing funds ($\alpha = \bar{\alpha}$) because their marginal change in value is positive: $\lambda = f_I R/q > 0$ when $R > 0$.

In order to analyse the comparative static effects between private funding $R$ and the level of maximum public funding share $\bar{\alpha}$, the optimal investment condition $C_R - (1 + \bar{\alpha})f_I/q = 0$ is totally differentiated with respect to $R$ and $\bar{\alpha}$ holding $q$ fixed:

$$C_R dR - \frac{(1 + \bar{\alpha})^2}{q^2} f_{II} d\bar{\alpha} - \frac{(1 + \bar{\alpha}) \bar{\alpha} R}{q^2} f_{II} d\bar{\alpha} - \frac{1}{q} f_I d\bar{\alpha} = 0$$

$$\Rightarrow$$

$$\frac{dR}{d\bar{\alpha}} = \frac{[(1 + \bar{\alpha}) R/q^2] f_{II} + [1/q] f_I}{C_{RR} - [(1 + \bar{\alpha})/q^2] f_{II}}$$ (4)

Raising the share rate $\bar{\alpha}$ means less private funding if the marginal output gains from forest investments are high ($f_{II} < 0$). Thus, in the general case the substitution between private investments and public financial aid ($dR/d\bar{\alpha} < 0$) occurs. However, the complementarity case occurs when marginal output gains from forest investments are small ($f_{II} \approx 0$) or when they are constant ($f_{II} = 0$).

Holding $\bar{\alpha}$ instead of $q$ fixed gives the own price effect of investments:

$$\frac{dR}{dq} = -\frac{[(1 + \bar{\alpha})/q^2] f_I - [(1 + \bar{\alpha})^2 R/q^2] f_{II}}{C_{RR} - [(1 + \bar{\alpha})/q^2] f_{II}}$$ (5)

The sign of $dR/dq$ is non-determined when $f_{II} < 0$, but negative own price elasticity is found ($dR/dq < 0$) when marginal output of investments are constant or small ($f_{II} \approx 0$). Note also that $dq/d\bar{\alpha} < 0$ when $f_{II} \approx 0$. The following econometric analysis is targeted to test these model implications.

**Translog cost function model of investment cost shares**

In early 1970s economic theory introduced a new broad class of production and cost functions, i.e. flexible functions that are local second order approximations to any arbitrary production or cost function. Much-used Cobb–Douglas and CES-type functions were too restrictive for many empirical applications. Flexible functions allow one to derive simultaneously the factor input elasticities with minimum parameter restrictions.

Suppose that the investment $I$ is characterized by the function of inputs $x$:

$$I = f(x), \text{ with } f' > 0, f'' < 0$$ (6)

The solution to the problem of minimizing the cost of specific investment rate, given a set of input prices $p$, produces the cost-minimizing set of investment input demands

$$x_i = x_i(I, p)$$ (7)

The total cost of investments is given by the cost function

$$C = \sum_{i=1}^{k} (I, p) = C(I, p)$$ (8)

If there are constant returns in production, then it can be shown that

$$C = Ic(p)$$ and $$\frac{C}{I} = c(p)$$ (9)

where $c(p)$ is the unit or average cost function of investment. The cost-minimizing investment factor demands are obtained by applying Shephard’s lemma, which states that if $C(I, p)$ gives the minimum total cost of investments, then the cost-minimizing set of factor demands is given by

$$x_i' = \frac{\partial C(I, p)}{\partial p_i} = \frac{I \partial c(p)}{\partial p_i}$$ (10)

Alternatively, by differentiating logarithmically, the cost-minimizing factor cost shares is obtained:

$$s_i = \frac{\partial \ln C(I, p)}{\partial \ln p_i} = \frac{p_i x_i}{C}$$ (11)
With constant returns to scale, \( \ln C(I, p) = \ln I + \ln c(p) \),

\[
s_i = \frac{\partial \ln c(p)}{\partial \ln p_i}
\]

(12)

In many empirical applications, the objects of estimation are the elasticities of investment factor substitution and the own price elasticities of demand, which are given as

\[
\theta_y = \frac{\partial^2 c/\partial p_i \partial p_j}{(\partial c/\partial p_i)(\partial c/\partial p_j)} \text{ and } \eta_y = s_i \theta_y
\]

(13)

By suitably parameterizing the cost function (8) and the cost shares (11) a system of \( K \) or \( K+1 \) equation econometric model is obtained that can be used to estimate these quantities.

The transcendental logarithmic (translog) function is the most frequently used flexible cost function in empirical work. A related alternative is the generalized Leontief function. However, the translog alternative is more general and flexible. The only general assumption is the convexity of cost function. The literature contains many valuable articles on the translog and related models (e.g. see Berndt & Christensen 1973, Berndt & Wood 1975, Christensen & Greene 1976, Berndt 1991, Chapter 9).

By expanding \( \ln c(p) \) in a second order Taylor series about point \( p = 1 \), one obtains:

\[
\ln c(p) \approx \beta_0 + \sum_{i=1}^{K} \left( \frac{\partial \ln c}{\partial \ln p_i} \right) \ln p_i + \frac{1}{2} \sum_{i=1}^{K} \sum_{j=1}^{K} \left( \frac{\partial^2 \ln c}{\partial \ln p_i \partial \ln p_j} \right) \ln p_i \ln p_j
\]

(14)

where all derivatives are evaluated at the expansion point. If these derivatives are identified as coefficients \( \beta_i = \partial \ln c/\partial \ln p_i \) and \( \delta_{ij} = \partial^2 \ln c/\partial \ln p_i \partial \ln p_j \) and the symmetry of the cross-price derivatives \( \delta_{ij} = \delta_{ji} \), is imposed, then the cost function becomes

\[
\ln c(p) = \beta_0 + \sum_{i=1}^{K} \beta_i \ln p_i + \sum_{i=1}^{K} \sum_{j=1}^{K} \delta_{ij} \ln p_i \ln p_j
\]

(15)

The cost shares \( s_i = \partial \ln c(p)/\partial \ln p_i \) must summate to 1, which requires, in addition to the symmetry restrictions already imposed,

\[
\sum_{i=1}^{K} \beta_i = 1, \sum_{i=1}^{K} \delta_{ij} = 0 \text{ and } \sum_{j=1}^{K} \delta_{ij} = 0
\]

(16)

The system of share equations \( s_i, i = 1, 2, \ldots, K \) provides a seemingly unrelated regression (SURE) model that can be used to estimate the parameters of the model. To operationalize the model, the restrictions in (16) and \( \delta_{ij} = \delta_{ji} \) are imposed and the problem of the singularity of the disturbance covariance matrix of the shares equations is solved. The first is accomplished by dividing the first \( K-1 \) prices by the \( K \)th price, thus eliminating the last term in each row and column of the parameter matrix. A nonsingular system is obtained by dropping the \( K \)th share equation.

**Data**

The data consist of yearly observations of NIPF investment outputs (or area proxies for them) in the years 1963–2000 (38 observations for each item listed below). NIPF forest investments can be made for the following purposes:

- preparation for natural and artificial regeneration (in hectares):
  - clearing of regeneration areas
  - soil preparation
- prescribed burning
- seeding and planting (in hectares)
- tending of seeding stands (in hectares)
- forest fertilization (in hectares)
- forest drainage (in kilometres)
- first-time ditching
- ditch cleaning and supplementary ditching
- construction and improvement of forest roads (in kilometres).

Data for corresponding NIPF costs and spent public financial support for these six investment activities were also available (Finnish Statistical Yearbook of Forestry, different years). All monetary variables were changed to real terms by dividing them by the consumer price index (base year 1990). Since the data set consists only of 38 yearly observations of each variable, a five-equation translog costs system would include too many parameters for efficient estimation. However, as this study was interested in allocation and in efficiency of public funding of private forest investments, the following three aggregate costs series were constructed that serve the targets: private costs (\( P \)), public aid and loans to private forest investments (\( A \)) and collective investment cost (\( C \)), which consists of common investments.
by many individual forest owners who share common forest roads and ditches. Investments in these receive extensive public funding to alleviate the investment incentive problem involved therein. The total cost are obtained by $TC = P + A + C$ and cost shares are $s_P = P/TC$, $s_A = A/TC$ and $s_C = C/TC$.

To derive the unit costs of collective costs ($p_C$) series $C$ was divided by the sum of kilometres of forest drainage, construction and improvement of forest roads. The unit costs private investment ($p_P$) were derived by dividing the private costs $P$ by the geometric mean of total hectares and kilometres of all investments. The unit costs or value of public aid and loans to individual private forest owners ($p_A$) were obtained by dividing series $A$ by the sum of hectares of investment in preparation for natural and artificial regeneration, seeding and planting, tending of seeding stands and forest fertilization. Different unit cost scales—per hectare, per kilometre or per geometric mean of these—were dictated by the data sources. Any attempt to transform kilometres to hectares (e.g. taking the square of kilometres) produced non-reasonable results.

This strategy of deriving unit costs of different types of forest investments naturally entails some measurement errors and overlap. Nevertheless, in broad perspective it portrays the costs structure of forest investments in Finland in years 1963–2000 rather well. Figs. 1–3 give plots of the series of investments, costs shares and unit costs in three different investment categories.

**RESULTS**

For the data in the model derived from eq. (14), $K = 3$. Including the possibility of scale economics in investments, the variables of investment volumes are added in the share equations $s_P$ and $s_A$ and the translog total cost equation is specified as follows:

$$s_P = \beta p_0 + \delta p_P \ln(p_P/p_C) + \delta p_A \ln(p_A/p_C)$$

$$s_A = \beta a_0 + \delta p_A \ln(p_P/p_C) + \delta a_A \ln(p_A/p_C)$$

$$\ln(c/p_C) = c_0 + \beta p_0 \ln(p_P/p_C) + \beta a_0 \ln(p_A/p_C) + \beta p \ln(I)$$

$$+ 0.5 \delta p p \ln(p_P/p_C)^2 + \delta p_A \ln(p_P/p_C) \ln(p_A/p_C)$$

$$+ 0.5 \delta a_A \ln(p_A/p_C)^2 + \varphi p p \ln(p_P I/p_C)$$

$$+ \varphi a_A \ln(p_A I/p_C) + 0.5 \varphi_c (\ln I)^2 \quad (17)$$

There are 10 parameters in the system (17) to be estimated with 38 observations for each variable. Estimation was done using the maximum likelihood estimates method. In preliminary estimations the total cost equation included also a time trend to capture the cost-reducing effects of technological change, etc. However, this was not statistically significant. Table 1 shows the results of the estimations. All coefficient estimates except for $\varphi_I$ were statistically significant at the 5% level. However, the results imply that strong scale effects are present in the system. When the system is estimated without the cost equation, i.e. the pure scale effects are not included, the log-likelihood function is 94.06, and the LR test for hypothesis $\beta_I = \varphi_I = 0$ is rejected with the test value of 72.27 ($p$-value = 0.000).

Positive values of $\beta_I$ and $\varphi_I$ mean that investment costs have increased in proportion to investment volume. The high estimate value of $\beta_I$ (2.19) shows that cost-increasing scale effects are present in the model. The symmetry condition $\delta p A = \delta a P$ was rejected for the model.

For the translog cost system estimates, the implied elasticities of substitution ($\theta_{ij} > 0$) and own price elasticities ($s_j/\theta_{ii} < 0$) are easily computed once the parameters of the model have been estimated:

$$\theta_{ij} = \frac{\delta_{ij} + s_j s_i}{s_i s_j} \quad \text{and} \quad \theta_{ii} = \frac{\delta_{ii} + s_i (s_i - 1)}{s_i^2} \quad (18)$$

They are first derived for the mean values of cost shares in the sample $\bar{s}$, then for year 2000 cost shares $s_i^{2000}$. These are important for policy analysis.
The figures shown in Table 2 imply that private (IP) and public supported private (IA) investments are substitutes for each other. As the public aid and loans rise (i.e. more financial aid is provided) the level of private investments decreases. However, private investments and private collective investments (IC) are complementary (−2.35). Private forest owners invest more in their own projects when the public support to collective projects (i.e. ditching and road construction) increases. Likewise, the investment support provided by the government to private individual forest owners (IA) and that to collective investment projects (IC) are strongly complementary (−12.35). Thus, as the public support to collective projects (e.g. roads and ditches) increases, more public support is also needed in the private individual projects.

The own price elasticities are all positive (see Table 2, diagonal elements). Private investments IP are very
price inelastic. The value of elasticity is close to zero (0.24). The own price elasticities of supported individual investments \( I_A \) and collective investments \( I_C \) are significant in economic terms. In particular, the collective investments are very price sensitive, with a value of 3.94, i.e. when more public funds are given to collective projects to reduce private unit costs, more forest investment projects are undertaken by private forest owners. The elasticities valued at year 2000 cost shares do not differ much from the mean cost share results. The year 2000 share estimates seem to amplify the effects already found. Note that empirical results obtained do not conflict with the derived theory implications. Investment output function seems to have different curvature conditions across the investment classes (i.e. condition \( f_{II} = 0 \) is relevant in some cases).

Table 1. Maximum likelihood estimates of translog cost functions of forest investments in Finland, 1963–2000. \( T = 38 \) (t-values in parentheses)

<table>
<thead>
<tr>
<th>Scale effects included</th>
<th>Scale effects excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_o )</td>
<td>( \beta_{P0} )</td>
</tr>
<tr>
<td>-5.00</td>
<td>-1.72</td>
</tr>
<tr>
<td>(-2.25)</td>
<td>(-5.74)</td>
</tr>
<tr>
<td>( \delta_{PP} )</td>
<td>( \delta_{PA} )</td>
</tr>
<tr>
<td>0.38</td>
<td>0.06</td>
</tr>
<tr>
<td>(15.94)</td>
<td>(2.43)</td>
</tr>
<tr>
<td>( \phi_I )</td>
<td>( \phi_{AI} )</td>
</tr>
<tr>
<td>0.56</td>
<td>0.59</td>
</tr>
<tr>
<td>(11.76)</td>
<td>(10.06)</td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>130.2</td>
</tr>
</tbody>
</table>

Table 2. Elasticities of substitution and own elasticities at mean cost shares and at year 2000 cost shares

<table>
<thead>
<tr>
<th>Mean cost shares, ( \bar{s}_i )</th>
<th>Year 2000 cost shares, ( s_{2000}^i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_P )</td>
<td>( I_A )</td>
</tr>
<tr>
<td>0.24</td>
<td>0.78</td>
</tr>
<tr>
<td>1.54</td>
<td>-2.35</td>
</tr>
</tbody>
</table>

\( I_P \): private investments; \( I_A \): private, individual investments with public support; \( I_C \): private, collective investments with public support.

Own price elasticities (\( s_i \, \partial s_i \)) are found on the diagonals.

The econometric analysis conducted in this context showed some interesting results concerning the merits of programmes and NIPF owners’ investment behaviour. The empirical analysis was based on a maximum likelihood estimation, the translog cost function specified for cost shares in three categories of forest investments in Finland from 1963 to 2000. The categories are the private own-financed investments, public supported private investments and private, multiparty investments with public support. The translog system approach gives the possibility of analysing the complementarity, substitution and scale effects in different investments categories.

The results showed that investments supported by government are complementary. However, government cost-sharing complements only partly the individual private investments. Some substitution is found between individual non-subsidized and public-aided investments. Strong collective forest investment incentives are found among forest owners in response to public investment aid. The investment scale effects led to increased costs, which may indicate overinvestments among NIPF owners. This result is supported by the fact that in some years funds targeted to investments were not entirely used. In general, these results show...

DISCUSSION

Government-funded financial support to private forest investments in Finland has been extensive since the 1960s. The economic allocation and efficiency of different programmes have not been analysed in terms of economic theory. Some theory implications were derived with a simple cost-sharing optimization model. The general outcome is the substitution between private investments and public financial aid. The results showed that investments supported by government are complementary. However, government cost-sharing complements only partly the individual private investments. Some substitution is found between individual non-subsidized and public-aided investments. Strong collective forest investment incentives are found among forest owners in response to public investment aid. The investment scale effects led to increased costs, which may indicate overinvestments among NIPF owners. This result is supported by the fact that in some years funds targeted to investments were not entirely used. In general, these results show...
that public funding and cost-sharing of private forest investments have had a non-negligible impact on the NIPF owners’ investment decisions.

Seen from the international perspective, very few papers exist on fund substitution. Most of the results are from USA and they typically link the wood supply and cost-sharing. Some results on the relationship between public cost-sharing and private investments are obtained as side-products. The paper by Hyberg & Holthausen (1989), based on survey data on Georgia NIPF landowners, reports that reforestation is related positively to cost-sharing. Investment cost effects are negative. Boyd (1984) and Royer (1987) obtained similar results with the same type of data and econometric methods from the earlier period. Brooks (1985) found, using panel data from 1950–1983 among southern states of the USA, that planting cost has major negative effects on acres planted but cost-share subsidy payments reduce the effects. de Steiguer (1984) found, using related panel data, that government cost-sharing payments do not affect the private autonomous tree-planting expenditures of NIPF investors. However, Cohen (1983), with data from 13 southern states of the USA in 1964–1978, reported that there is a trade-off between public funding and private investment in forestry. Note that these papers do not handle the investment substitution in an explicit system estimation framework.

However, on the general level the results obtained are preliminary and some problems remain. The present data set is quite small and the conducted aggregation is bias sensitive. Some preliminary estimation work with a smaller data set and a different aggregation approach confirmed that the reported results are only robust in a qualitative sense. Strong complementarity was still found, although the numerical estimates differed over different samples. The translog system model contains some economic assumptions and restrictions that are often violated in empirical work. In the present case the symmetry condition \( \delta_{Pd} = \delta_{AP} \) was rejected in statistical testing. This casts some doubts over the efficiency of the translog modelling alternative.

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