THE STRUCTURE OF SOUTHERN INDUSTRIAL ROUNDWOOD SUPPLY

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ABSTRACT

In this paper we introduce the use of duality techniques to the evaluation of biological forest production processes. These techniques potentially allow the direct estimation of economically consistent production parameters such as short- and long-run supply elasticities, input demand elasticities, and cross-price elasticities. To showcase the use of these techniques, we examine industrial roundwood production structure in the coastal plain of the southeastern U.S. and derive its short run supply and demand characteristics.

INTRODUCTION

In the past 15 years, numerous studies have been published which use dual profit and cost function models to examine production technologies. Many models of agriculture (e.g. Binswanger 1974; Lopez 1980; 1984; Shumway et al. 1988) and of wood products industries (e.g. Singh and Nautiyal 1986; Stier 1980; Wear 1987) have been developed which take advantage of the dual to assess such important issues as production structure, input use, and technological progress. The latter studies, in particular, have provided detailed insight to the derived demand for and the substitution possibilities between stumpage and other factors of production, returns to scale, and technical change bias.

Unfortunately, the application of duality techniques has not crossed over to the analysis of biological forest production processes. Economic analyses of forest production have been limited to either fairly simple plantation-type models of limited tree species (Chang 1984; Nautiyal and Couto 1981) or aggregate models which do not separate out stumpage outputs and inputs (Newman and Wallace 1985). Stumpage supply and demand models have for the most part been unable to derive consistent dynamic models because of difficulties in depicting supply (Newman 1987). As a result, the wealth of information that could be developed with the knowledge of a technical forestry production function remains untapped.

Our objective in this paper and the order of its presentation is twofold. First, we want to show how duality techniques can be applied to the biological forestry situation. We discuss the necessary conditions and some basic background for their use and some of the assumptions necessary to apply them

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in the forestry situation. Second, we use a dual model of the timber production technology for a fairly homogeneous region of the country as a case study to show the potential applicability of the techniques. For our example, we use the case of industrial forest management on the coastal plain of the southeastern U.S. The only results we derive here relate to short-run supply elasticities for softwood products and demand elasticities for regeneration inputs. We compare our results with existing estimates which use simultaneous equation, market models. We close with a discussion of future research areas and applications.

METHODS

Forests produce numerous outputs but we will focus on only pulpwood and solid wood stumpage. As with all processes, inputs are used in combination to produce a set of outputs. A production function, generalized to the multi-output case, is the transformation function. This function defines the set of efficient input:output combinations for a production technology. The transformation function can be represented by:

\[ T(X,Y) = 0 \]

where \( X \) is a vector of inputs (capital, labor, energy, etc.) and \( Y \) is a vector of outputs (pulpwood and solid wood). Setting the equation equal to 0 means that there is no waste in the system (i.e., just enough inputs are used to create the outputs).

We would like to estimate the transformation function directly but, in practice, we are often frustrated from doing this by either the unavailability or impracticality of collecting raw input data. This is one of the areas where the advantage the dual comes into play. The duality properties of optimization allow us to recreate the transformation function using an estimated profit function instead. Whereas the transformation function is defined in terms of input and output quantities, the profit function is defined in terms of input and output prices. These data are, quite often, more readily available and more reliable than input and output quantities. We define the profit function as:

\[ \Pi = \pi(p,q) \]

where \( \Pi \) is profit, \( p \) is a vector of input prices and \( q \) is a vector of output prices. Once we have defined a profit function, we can take advantage of its basic properties to derive a great deal of relevant information. The derivative properties of profit functions also allow us to estimate the supply of outputs and demand for inputs directly as a function of input and output prices. Following Hotelling (1932) the derived supply of a product and derived demand for an input are, respectively:

\[ \frac{\partial \Pi}{\partial q_i} = y_i \]

\[ -\frac{\partial \Pi}{\partial p_j} = x_d \]
Several variants of the profit function exist. For time series applications, trend variables are often applied to test for various kinds of technological progress (e.g., Stier 1980). In addition, since producers may be unable to adjust all inputs and outputs instantaneously, a restricted profit function may be applied (Chambers 1988; Squires 1987). For example, we may not expect capital tied up in plants and equipment to adjust rapidly to changing market conditions. In such a case, the profit function may be formulated with levels of the capital input (K) held fixed. We then define the restricted profit function combining input and output prices and capital quantities:

\[ \Pi' = \pi'(p, q; K) \]

where \( p \) no longer contains the price of capital. A more complicated extension of the model would explicitly consider the adjustment mechanism, allowing for slower adjustments for some factors or outputs.

**APPLICATION TO TIMBER PRODUCTION**

The aggregate production process for southern forestry differs markedly from previous applications in the literature, in part because of the extended forest production period. Regeneration inputs and timber outputs are separated by many years, 15-25 in the case of pulpwood and 30-50 for sawtimber. If we were to ignore the time lag between inputs and outputs, a simple transformation function for timber could simply contain sawtimber (\( Y_s \)) and pulpwood (\( Y_p \)) outputs and regeneration (R) and land (L) inputs.

\[ T(Y_p, Y_s, R, L) = 0 \]

However, we cannot ignore the displacement of inputs and outputs across time. To address this problem we can view the situation slightly differently. Since timber production takes place over a number of years, we can define an intermediate product in the timber production process, timber growing stocks. At a regional level, growing stocks of sawtimber can be called an intermediate product that is augmented by (1) regeneration inputs and (2) an appreciation process, biological growth; and which is depleted through mortality at one level and through stumpage removals (output). Growing stocks are thus analogous to buildings and equipment in the manufacturing sectors. They are a capital stock which does not adjust instantaneously to market changes but which does change through investment and depreciation over time. Forest land can be similarly viewed as a factor of production which does not adjust to full-equilibrium levels in the short-run (See figures 1 and 2 for a schematic comparison of manufacturing and forest production processes). Thus, in any given period a producer makes harvesting and regeneration decisions based, in part, on the existing levels of growing stocks and land on hand and on the relative prices of regeneration effort and output prices. This defines the following restricted profit function.

\[ \Pi' = \pi'(r, q_p, q_s, G, L) \]

where \( r \) is regeneration cost, \( q_p \) is pulpwood price, \( q_s \) is sawtimber price, and \( G \) is growing stock quantities.
The derivative property of the profit function, described in equations [3] and [4], allows us to define short-term pulpwood and sawtimber supply and regeneration demands as functions of the same independent variables.

\[ Y_i = \phi_i(r, q_p, q_s, G, L) \]

\[ R = \theta(r, q_p, q_s, G, L) \]

These derived supply and demand functions can be used to analytically derive the own price and cross price elasticities for sawtimber and pulpwood supply along with the effect of levels of growing stock and land on supply.

**EMPIRICAL WORK**

In order to perform estimations of the profit and derived supply functions, we constructed a cross-sectional, county-level, data base for industrial ownerships in the coastal plain of the southeast. The majority of the data -- growing stock removals, levels of growing stock, acres planted, and forest area-- came from the most recent FIA surveys for each state. In addition, we developed a county-level price index for regeneration based on a data base containing costs for the FIP program in 1982. These data, while taken from a different ownership type, were assumed to reflect regional variations in regeneration costs. We limited our analysis to the coastal plain in order to address a relatively homogeneous timber-production technology.

We defined an empirical profit function using a Diewert-Generalized Leontief framework, a commonly used functional form. We estimated the restricted profit function, along with a demand equation for planted acres and supply equations for sawtimber and pulpwood using generalized three stage least squares techniques. The details of the empirical model can be found in a working paper by the authors (Wear and Newman 1989) but we will focus the remainder of the paper on some elasticity results of the model.

The results of estimating these functions were used to estimate supply and demand elasticities along with cross-elasticities with respect to input and output prices. These values are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Sawtimber</th>
<th>Pulpwood</th>
<th>Regeneration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawtimber</td>
<td>0.143</td>
<td>-0.121</td>
<td>-0.022</td>
</tr>
<tr>
<td>Pulpwood</td>
<td>-0.183</td>
<td>0.341</td>
<td>-0.158</td>
</tr>
<tr>
<td>Regeneration</td>
<td>0.026</td>
<td>0.122</td>
<td>-0.148</td>
</tr>
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</table>
Table 1 shows both sawtimber and pulpwood supply to be highly inelastic as well as the demand for regeneration. Note that, the homogeneity property of demand functions forces the rows in table 1 to sum to zero. Interestingly, pulpwood is found to be more elastic than sawtimber supply. This contrasts with Newman’s (1987) recent supply and demand results which showed pulpwood to be much more inelastic than solidwood. One reason for this reversal may be that Newman’s study used all ownerships while this study uses only industrial forest land. Since nonindustrial (NIPF) owners are less likely to gear their management policies to the lower valued pulpwood production, they are less responsive to price shifts in pulpwood. However, industrial management is often directly intended for pulpwood and therefore production will be more directly tied to price changes. Similarly, pulpwood can be produced from growing stocks in nearly any condition while sawtimber is produced only from larger trees so that short-term output increases are more difficult.

Another interesting difference between these results and Newman’s is that both sawtimber and pulpwood are technical substitutes in output. Newman found, as has work in Sweden (Brannlund et al. 1985), that pulpwood was a complement in sawtimber production (pulpwood output increased when the price of sawtimber increased), while sawtimber was a substitute in pulpwood production. As noted in those studies, this asymmetry violated the second order conditions of a continuous profit function as the cross-price slopes should be equal. In our example, we constrain the cross-price coefficients to be equal so that the asymmetry found in these other studies does not occur.

The highly inelastic price response of regeneration indicates that industrial owners tend to base their planting decisions on factors other than price. Regeneration also responds only weakly to changes in sawtimber and pulpwood prices. These results correspond to other studies that have tried to tie regeneration behavior to prices (de Steiguer 1984; Royer 1987). If the results from our study carry over to NIPF ownerships, they highlight the potentially small short-run impacts of measures designed to increase forest investments by lowering costs. Input price does not appear to be driving regeneration investments to a great extent and a fuller appreciation of ownership factors would be necessary to implement effective investment policies.

Related to the regeneration elasticities shown in table 1, we can also calculate regeneration demand elasticities with respect to changes in outputs. For sawtimber, a 1% increase in removals brings about an elastic, 1.12% increase in regeneration. For pulpwood, a 1% increase in removals only brings about an inelastic, 0.78% increase in regeneration. The reason for these differences may be that when timber is harvested for sawtimber, this generally involves a clearing of the stand and leaving land readily available for regeneration. Pulpwood, however, is often harvested during thinning and other practices and therefore may not lead directly to the need for regeneration.

DISCUSSION

In this paper we present a brief introduction to the application of duality techniques to the forest production process. The presentation is cursory at best and those interested in pursuing the methods further should look to the
articles and books we cited. Although the material can be technically quite demanding, the payoff in applying these methods can be better, more consistent estimates of relevant production information.

There are a number of additional estimates which can be derived from a restricted profit function series of equations. Besides the partial equilibrium elasticities that we discuss, we can also estimate the Hicksian, compensated elasticities. These values become useful when discussing welfare effects from price changes as a result of policy shifts. The theory also allows us to move beyond the short-run estimates that we have shown in this paper, to long-run equilibrium estimates for the variables. In order to do this the shadow prices for the quasi-fixed variables, land and growing stock, must be derived. When these shadow prices are compared to current market prices for the inputs, they give us the degree that scarcity is currently felt in the market. When they are added to the estimates of the restricted profit model, we can derive the long-run Marshallian elasticities.

This research has a number of useful applications. The integration of forest production into large scale economic models has been hampered by a lack of relevant elasticity information. As a result, the analysis of macroeconomic impacts of government forest policies has been forced to rely on rules-of-thumb and guesses at basic production relationships. Using these techniques, we believe that we will be able to investigate some of the thornier empirical issues of forest economics that have been difficult to assess using other partial-equilibrium methods. These include issues such as differentiating responses of NIPF vs. industrial forest production, and long-term economic impacts from government taxation and subsidy policies.

LITERATURE CITED


