Abstract

Örjan Furtenback. *Fuel substitution in district heating plants and CGE modeling with a forest resource*. Licentiate Thesis.

This thesis contains two papers.

Paper I: *Demand for waste as fuel in the Swedish district heating sector: a production function approach*
This paper evaluates inter-fuel substitution in the Swedish district heating industry by analyzing almost all the district heating plants in Sweden in the period 1989 to 2003, specifically those plants incinerating waste. A multi-output plant-specific production function is estimated using panel data methods. A procedure for weighting the elasticities of factor demand to produce a single matrix for the whole industry is introduced. The price of waste is assumed to increase in response to the energy and CO_2 tax on waste-to-energy incineration that was introduced in Sweden on 1 July 2006. Analysis of the plants involved in waste incineration indicates that an increase in the net price of waste by 10% is likely to reduce the demand for waste by 4.2%, and increase the demand for bio-fuels, fossil fuels, other fuels and electricity by 5.5%, 6.0%, 6.0% and 6.0%, respectively.

Paper II: *Towards a dynamic Ecol-Econ CGE model with forest as biomass capital*
This study presents a Dynamic Computable General Equilibrium model that combines economic and ecological aspects of forest biomass. A framework is introduced for modeling the growth of a biomass stock which interacts with economic sectors. Harvest of and demand for forest products and forest amenities are determined endogenously in an inter-temporally consistent way. The idea is based on a Markovian growth model of the forest. The study demonstrates an approach for incorporating non-market values of forests, such as carbon sequestration, recreation and biodiversity, into a growth model. A simulation illustrates harvest behavior when the economy is subjected to shocks.

Key words: Cobb-Douglas production function, factor demand, inter-fuel substitution, waste management, Dynamic CGE, Markovian growth, Ecosystem modeling, Inter-temporal optimization, Infinite-horizon equilibria

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Articles appended to the thesis

The thesis is based on the following articles, by Örjan Furtenback (Article I reproduced under permission by *Journal of Waste Management*):

I Demand for waste as fuel in the Swedish district heating sector: a production function approach.

II Towards a dynamic Ecol-Econ CGE model with forest as biomass capital.

Contents

Fuel substitution in district heating plants and CGE modeling with a forest resource

Articles I–II

1 Introduction

The forest resource in Sweden has traditionally been used in saw mills, board industry, and paper and pulp industries. Since the 1980s, District heating, using forest bio-mass residues as input in the production of heat, increased significantly. Also, amenity values, such as recreation and carbon sink services have become increasingly important.

The use of the forest resource has changed over time, from being primarily an input to saw mills and pulp and paper production, to also include provision of a wide array of amenities, and as a source of bio-energy.

Figure 1 shows how forest bio-mass resources flow from the forest owner into the forest industry (saw mills, board industry, and pulp industry), between agents within the forest industry, and into the final products industry in 2004. Forest industry agents are represented by rectangular boxes, boxes with rounded bottoms represents storage of specific bio-mass, input from forest owners enter from the left, and output to the final products industry resides on the right hand side. Shaded areas indicate quantities used for energy purposes. Note that values indicated at arcs are in Mt dry bio-mass matter. The data is based on Nilsson (2006).

As can be deduced from figure 1, the 32,650 Mt of dry matter is broadly used as follows: one quarter attributed to sawn goods, one third to pulp, one-hundredth to boards and one tenth to district heating and briquettes or pellets. Approximately one third is used in the forest industry, mainly to heat for drying and to some extent to produce electricity.

The value of forest raw material as a source of energy has increased considerably since the oil crises of the 1970s and continues to increase with increasing prices of fossil fuels. The expansion of bio-fuels has been extensive in recent years and will most likely continue.

The European Union has intensified its energy and climate change ambitions and, as a Member State, Sweden is expected to make an effort to meet these ambitions. The Commission of the European Communities, SEC (2008) 85/3, Impact Assessment, originates from an agreement between the EU Member States and contains proposals for how the burden of reaching energy and climate targets could be shared amongst nations. Taken together the Member States have agreed to reduce greenhouse gases by at least 20 percent by 2020 compared to 1990, and provided that a comprehensive international agreement on reductions comes about, the target is set to a 30 percent reduction. In addition, the Member States decided that renewable energy should constitute 20 percent of total energy consumption within the EU, including a 10 percent bio-fuels target for transports. The legally-binding targets amongst EU's Member States vary and the targets assigned for Sweden is a 17 percent reduction of greenhouse gases emissions compared to 2005 and a share of renewable energy amounting to 49 percent by 2020, up from 43.9 percent in 2007 (Swedish energy Agency 2009).

The arguments used by countries for justifying this development are mainly connected to positive environmental and economic effects, that could be summarized as

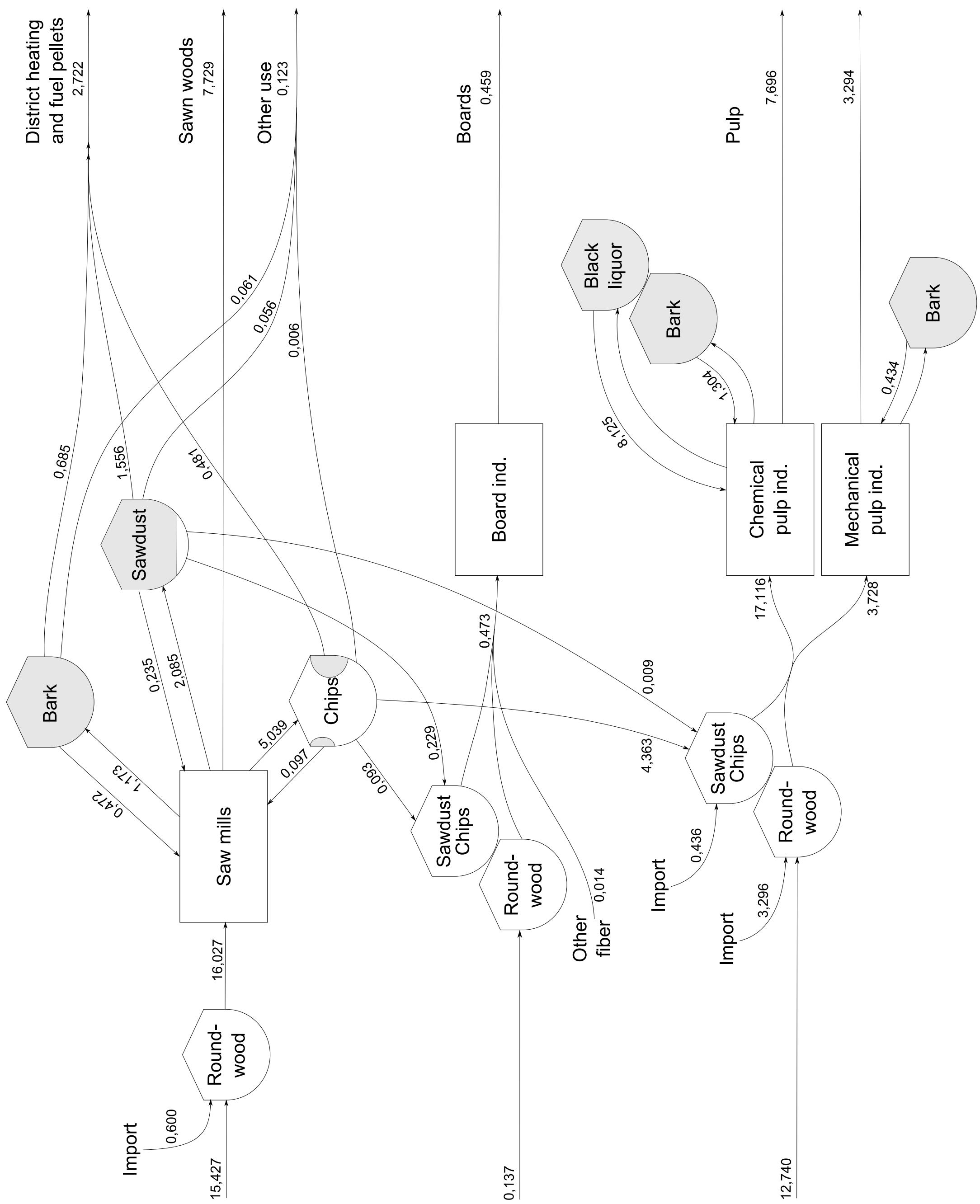

Figure 1: Commodity inputs to the forest industry and the flow through process to final products in 2004. Modified from Nilsson (2006).

in Lundgren et al. (2008):

- Climate effects
- Environmental effects (other than climate effects)
- Energy security effects
- Net economic effects (e.g., on employment and income)

If the combined impact of these effects has a nonnegative net effect on welfare, the conversion from fossil energy sources to bio-energy sources is justifiable from a societal point of view.

Forest raw material is expected to be sufficient to cater for the demand of traditional products such as sawn goods, paper and packaging, district heating, and for new purposes such as electricity generation and fuels in the transport sector. Furthermore, the Swedish government (the department of agriculture) recently announced a proposition to increase the role of the forests as a carbon sink as well as an increase in the use of forest biomass for energy (Government Bill 2007/08:108, 2008).

In short, the claim on forests and forest resources have increased significantly both from the traditional forest sector and from entirely new groups.

Next partial equilibrium and general equilibrium modeling are discussed in brief. The purpose of this is to familiarize the reader with some of the key concepts of this thesis. Then the two papers will be introduced and fully presented.

2 Assessing the effects of environmental policy - Partial and General Equilibrium

This thesis contains two papers. The two papers are quite disparate in methodology but share some common features. The common features can be summarized as:

- The utilization of forest and other non-fossil recourses
- Environmental policies and their implications

The first part of this thesis uses partial equilibrium analysis of policy decisions influencing the environment. Partial equilibrium models assume that the feedback from sectoral changes to aggregate variables is negligible thus allowing a more detailed analysis of the effect a specific policy might have on commodity markets (Lundmark and Mansikkasalo 2009). The modeling framework has its foundations in applied production economics (see e.g. Chambers 1988). Partial equilibrium analysis *of one market* is based on the assumption that all relevant variables except the price in question are constant. The focus is on the impact of a policy in one market, without worrying about second round effects from other markets. In many cases partial equilibrium analysis is debatable, but in others it is a very useful tool. Generally, the more narrowly the market is defined, the more appropriate PE analysis is. The analysis considers the substitution effects of inputs used in the district heating industry resulting from the introduction of a tax on incineration of waste, SFS 2006:592 (2006), motivated for curbing CO_2 emissions. It is assumed that the net price of waste for the waste incineration industry changes in response to the introduction of a tax on the incineration of waste, and that the tax will not cause significant changes in the price of input substitutes (fossil fuel, bio-fuel, electricity) or output substitutes (heating with fossil fuel, bio-fuel, electricity). The study is an econometric examination of the district heating sector where bio-mass enters as an input fuel and is similar to Brännlund and Kriström (2001), where the impact of energy taxation on the Swedish district heating industry was examined, but without specifically considering waste as an input to the incineration industry.

Figure 1 shows that the forest industry and final product industry are highly interconnected. General equilirium effects might be present in such a case. The second part of the thesis takes this into account and attempts to introduce a more holistic approach to the economic analysis of the use of forest products. A framework for evaluation of ecological aspects of the forest in combination with the economy is introduced. The study does not investigate a specific policy, but rather introduces a tool for policy analysis. Examples of policies could be, significant increased use of forest as a bio-fuel, including forest carbon sequestrating capability, or setting forest land aside in order to increase recreation or biodiversity values.

Many CGE models are static: they model the reactions of the economy at only one point in time. For policy analysis, results from such a model are often interpreted as showing the reaction of the economy in some future period to one or a few external shocks or policy changes. That is, the results show the difference (usually reported in percent change form) between two alternative future states (with and without the policy shock). The process of adjustment to the new equilibrium is not explicitly represented in such a model, although details of the closure (for example, whether capital stocks are allowed to adjust) lead modelers to distinguish between short-run and long-run equilibrium. Seminal work in this area include Johansen (1960) who formulated the first empirically based, multi-sector, price-endogenous model analyzing resource allocation issues, and Harberger (1962), which was the first to investigate tax policy questions numerically in a two sector general equilibrium framework. Mathiesen (1985) formulated the problem of solving a CGE by stating the CGE as a system of weak inequalities with corresponding variables featuring complementary slackness with the inequalities. This is commonly referred to as a "Mixed Complementary Problem" (MCP) in mathematics.

Dynamic CGE models explicitly trace each variable through time, often at annual intervals. These models are more realistic, but more challenging to construct and solve, they require for instance that future changes are predicted for all exogenous variables, not just those affected by a possible policy change. The dynamic elements may arise from partial adjustment processes or from stock/flow accumulation relations, for example between capital stocks and investment. An educating example on how to construct a dynamic CGE model is Lau et al. (2002), which poses the well known Ramsey model, Ramsey (1928), in the MCP setting.

This part of the thesis presents a dynamic CGE analysis and treats forest as a biomass capital stock which is related to the flow variables harvest and growth. Harvest of the forest, and amenities provided by the standing stock of forest, enters into the economy specified by the preference system's demand functions. The dynamics of the model is governed by a Markovian growth process of the forest, and harvest is determined endogenously.

3 Summary of articles

3.1 Demand for waste as fuel in the Swedish district heating sector: a production function approach

This study investigates fuel substitutions in Swedish district heating plants due to changes in the price of waste. It assesses the extent to which the Swedish district heating industry is likely to change its choice of fuel if the price of waste changes. While the operators of waste incinerators charge fees for handling and disposing of waste, it also provides fuel. This industrial enterprise is modeled as a multi-output production system, in which the plants both generate energy (for district heating) and provide a waste disposal service. The waste incinerator plants are therefore considered as bearing extra costs for the handling and disposal of the waste they receive as a fuel input. This implies that the waste incineration industry incurs a net cost for the waste it utilizes. The net price of waste for the waste incineration industry is assumed to change in response to new taxes on waste incineration SFS 2006:592 (2006).

A multi-output plant-specific production function is estimated using panel data methods. A procedure for weighting the elasticities of factor demand to produce a single matrix for the whole industry is introduced. The price of waste is assumed to increase in response to the energy and CO_2 tax on waste-to-energy incineration that was introduced in Sweden on July 1, 2006. The study reveals that price changes for waste fuel have the expected result, i.e. negative own-price and positive cross-price elasticities. Analysis of the plants involved in waste incineration indicates that an increase in the net price of waste by 10% is likely to reduce the demand for waste by 4.2%, and increase the demand for bio-fuels, fossil fuels, other fuels and electricity by 5.5%, 6.0%, 6.0% and 6.0%, respectively.

3.2 Towards a dynamic Ecol-Econ CGE model with forest as biomass capital

The use of Computable General Equilibrium (CGE) models in analyses of the forest sector has been motivated by the importance of links between the forest sector and the rest of the economy (Haynes et al. 1995). In regions where the forest sector is an important contributor to employment and gross domestic product, the effect of changes in the forest sector on the economy may be of significant interest. In, for example, Binkley et al. (1994) a CGE model was used to analyze the economic impact of reductions in the annual allowable cut in the Canadian province of British

Columbia, where the forest industry is a major component of the economy. In addition, the Global Trade Assessment Project (GTAP) model has been used as part of an Asia-Pacific Economic Cooperation (APEC) study to assess the effects of the removal of specific non-tariff barriers to forest product trade on a country's gross domestic product, welfare, and trade (New Zealand Forest Research Institute 1999).

This study presents a Dynamic CGE model, suitable for policy analysis, which combines simple economic and ecological aspects of the forest biomass. Biologists point out that biological populations can seldom be accurately described by the aggregate biomass without paying attention to the internal structure, including variables such as the age-class distribution (Getz and Haight 1989). Therefore, the model presented here has a detailed age-structured representation of growth and harvest of biomass stocks, interlinked with the rest of the economy. Harvest and demand for forest products and forest amenities are determined endogenously in an inter-temporally consistent way. The general idea is Markovian growth[1]. The possible policy instruments include taxes, subsidies and tariffs. Questions regarding the value of carbon sequestration and the cost of setting aside special parts of forest land for recreation can also be addressed. Further, it is possible to impose restrictions on forest harvests, in accordance with prevailing regulations.

The ecological part of the model is based on the forest growth model in Sallnäs (1990), which has been used to develop software, called EFISCEN (Schelhaas et al. 2007), by the European Forest Institute that is used for projections of forest resources. Input to EFISCEN is based on national forest inventories and input data are available for 31 European countries. The EFISCEN software generates an initial Area Distribution Vector, describing the state of the forest, and a Transition Probability Matrix, which describes the growth process of the forest.

The study demonstrates an approach for incorporating non-market values of forests, such as carbon sequestration, recreation and biodiversity, into a growth model. A simulation illustrates harvest behavior when the economy is subjected to shocks.

[1]The Markov growth model is a well-known mathematical model for the random evolution of a memoryless system. That is, one for which the likelihood of a given future state, at any given moment, depends only on its present state, and not on any past states.

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