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PULP AND PAPER INDUSTRY IN TRADITIONAL AND NEW MARKETS – A FUZZY INPUT-OUTPUT ANALYSIS

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Abstract: The global business environment of the pulp and paper industry (PPI) has changed drastically during past decades. This paper focuses on analyzing the linkages between PPI and other industries in Brazil, Finland, and the United States. We identified the most important inter-industry linkages and analyzed possible differences between countries, and over time. We also predicted Finland's input-output structure using fuzzy linear models. The results suggest that there are distinct differences across countries and also over time. It seems that the global changes in pulp and paper markets have changed the purchase "recipe" of PPI in all of the countries investigated. Fuzzy input-output analysis was found to be a useful forecast method, although further research is needed prior to any generalizations.

Keywords: Input-output analysis, Fuzzy linear systems, Pulp and paper industry

1. Introduction

The pulp and paper industry (PPI) has experienced major structural changes in the 2000s. Examples of the changes include the substitution of printed media for electronic communication technologies, the shift in advertising expenditures from print media to electronic media, innovations in clonal forestry, and the increased importance of China, Brazil, India and other emerging market economies (see, e.g., Figueiredo, 2010; Hurmekoski and Hetemäki, 2013). One consequence is that the production of pulp and paper is gradually moving from the mature markets of North America, Western Europe and Japan to e.g. Southeast Asia and South America, where the demand for paper and board is increasing and cost-effective raw materials are available. In the 2000s, China with its low labor and energy costs and booming paper and board consumption has become a particularly important player in the industry, while several paper machines and mills have been closed in Western Europe, where the industry has suffered from overcapacity and profitability problems (Valtonen, 2008). South America, especially Brazil, has become one of the most important wood pulp exporters due to its eucalyptus plantations (see, e.g., Hujala et al., 2013). Yet another significant structural change is that the operating environment of the PPI has become more complex, cross-sectoral and interlinked with other sectors (Hurmekoski and Hetemäki, 2013).

The aim here is to describe the economic impact of the PPI on other industries in three countries (Brazil, Finland and the United States) using Leontief's input-output matrices. The selected countries are important global paper and/or pulp producers at different levels of economic development. We are particularly interested in the potential changes in inter-industry linkages between PPI and other industries, and in the role of the PPI in nation's economy between the mid-1990s and mid-2000. We will also predict Finland's input-output structure for PPI and four other industry sectors in 2010 using fuzzy numbers. To our knowledge, this study is one of the first ones to apply fuzzy input-output analysis on real data and to report predictive accuracy of fuzzy Leontief input-output applications.

The next section gives an overview about current megatrends affecting PPI. Section 3 presents the theoretical background of the input-output analysis and fuzzy linear systems. Section 4 gives an overview of the data collection, presents the results of the input-output analyses and discusses the main findings. Section 5 concludes the paper.

2. Current trends affecting PPI

Three so called megatrends seem to be of high importance in the PPI markets, that is globalization, technological development and environmental awareness. Some recent studies (Jonsson, 2011; Toppinen et al., 2010; Hetemäki et al., 2010) emphasize the significance of globalization and technological development for the PPI. Sideri (1997, p. 38) gives the following definition of globalization: *"Globalization is essentially a process driven by economic forces. Its immediate causes are, in this order, the spatial reorganization of production, international trade and the integration of financial markets."* The regional redistribution of production and consumption of pulp and paper products is obvious. The increased importance of emerging markets as producers and consumers is evident as is the decreased importance of North America and Western Europe. Reorganization in the international trade of chemical pulp has occurred as well due to Latin America's recent success in the pulp markets and China's insatiable demand for paper making fibers.

According to Larsen (2006), the most important areas in technological development are information technology, biotechnology, nanotechnology and energy. At least the first two areas are clearly causing structural changes in pulp and paper production and consumption. The production of newsprint has collapsed in the United States most likely due to the substitution effect of electronic media and the shift in advertising expenditures from print media to electronic media, and innovations in cloning eucalyptus have greatly helped Latin America to gain its position as one of the leading chemical pulp producers (Figueiredo, 2010).

Increasing environmental awareness also has its impacts on the PPI since producing pulp, paper and paperboard has significant impacts on environment in different stages of the product life cycle (forestry, pulping, bleaching, paper and board manufacturing, transportation etc.) (Frota Neto et al., 2008). For example, recovered paper is nowadays the leading raw material in paper and paperboard production. This development has been facilitated by technological progress, for example, in the areas of deinking and screening of impurities (Diesen, 2007), the good price competitiveness of recycled fiber and Asia’s need for fiber (see. e.g., Arminen et al., 2013). Environmental consciousness and regulation have also contributed to the increase in the demand for recovered paper (see, e.g., Huhtala and Samakovlis, 2002; Samakovlis, 2003; Berglund et al., 2002; Berglund and Söderholm, 2003; Arminen et al., 2013). Moreover, according to Kando and Buongiorno (2009), the efficiency in wood and virgin fiber utilization has increased in most of the OECD countries between 1961 and 2005. The results most likely reflect the significance of conserving scarce forest resources since wood utilization efficiency was lower in countries that have vast forest resources. The impact of environmental issues is not limited to production and the use of paper making fibers: according to Toppinen et al. (2010), increasing awareness of environmental and social issues has led corporate social responsibility to become a high profile issue in the forest industry’s foreign direct investments, and Jonsson (2011) notes that chemical pulp producers could manufacture new products in integrated bio-refineries and, hence, profit from the growing bio-energy industry. Also, legislation and risen consumer awareness on environment issues have pressurized companies to develop their logistics networks (see, e.g., Frota Neto et al., 2008) and directed them toward green supply chain management and purchasing (see, e.g., Eltayeb and Zailani, 2010; Routroy and Pradhan, 2012; Dubey et al. 2013).

According to Hänninen (2004) there is a growing interest in short-term economic forecasts due to changes in the world's economies. Hänninen (2004) also states that the PPI must be aware of alternate future scenarios when making decisions and, thus, there is a need for forecast models and forecasts. According to the literature review of Toppinen and Kuuluvainen (2010) about the forest sector modeling in Europe, it seems that there are only few econometric studies that have attempted to forecast forest sector development. In addition, the partial equilibrium models most often used to forecast the future of the forest sector do not cope well with the structural changes and uncertainties concerning model parameters (Hurmekoski and Hetemäki, 2013). Therefore, it would be important to perform sensitivity analysis in order to account for the uncertainties (see, e.g., Kallio, 2010).

The first aim of this paper is to analyze whether the megatrends discussed above have affected the inter-industry linkages between PPI and other industries in three different countries. An interesting question is, if all of the trends are equally important. Furthermore, we contribute to the existing literature on short term economic forecasts of forest product sector by predicting Finland's input-output structure for PPI and four other industries in 2010. Fuzzy input-output analysis enables us to take into account some level of uncertainty concerning the input parameters of our model.

3. Fuzzy input-output analysis

The input-output model was originally developed by Wassily Leontief in 1936. It is an analytical tool that can be used in various economic problems such as identifying the key sectors of an economy or revealing possible bottlenecks during the expansion of production (see, e.g., Miernyk, 1965). The input-output analysis is based on the data organized in the form of a table illustrating the structure of a nation's (or region's) economy at a given point in time. The input-output table depicts the volumes of purchases and sales among industries. Thus, it shows how dependent each industry is on all the other industries in the economy.

The structure of an input-output table is illustrated by Table 1.

[Table 1 near here]

Each row of the input–output table reports the value of the industry's outputs, and the inputs are represented in the columns. Non-industrial inputs, such as the compensation for employees (LABR) and gross operating surplus (GOS) are aligned below the matrix. An array of column vectors called final demands, such as the household's final consumption (HHFC), changes in inventories (CHINV) and exports (EXP) are on the right hand side of the matrix. The total gross output of the industry *n* equals its total input.

The basic equations of the input-output model can be expressed as follows (e.g., Miernyk, 1965). The total gross output x_i of an industry is the sum of its intermediate outputs x_{ij} and the final demand d_i:

$$x_{i1} + x_{i2} + \cdots + x_{in} + d_i = x_i \ . \qquad (1)$$

The sum of intermediate outputs equals the total volume of sales from the industry in question to other industries. Final demand d_i captures the direct sales from the industry to households, nonprofit institutions and general government, plus the sum of gross fixed capital formation, changes in inventories, valuables and exports. Imports are either subtracted from the exports (so-called total input-output tables) or they are seen as inputs to the industry (so-called domestic input-output tables).

An important concept related to the input-output analysis is the technical coefficient. These coefficients represent the direct purchases of each industry from every other industry per one monetary unit of output. For example, in 2005 Brazilian PPI purchased from chemical industry for \$0.081 and from forest industry for \$0.059 per one US dollar of output. Thus, in a sense, the technical coefficients are the recipe used in an industry.

Based on Table 1, the technical coefficients are calculated as

$$a_{ij} = \frac{x_{ij}}{x_j} . \tag{2}$$

Substituting (2) in (1) yields

$$a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + d_i = x_i . \tag{3}$$

In matrix form we have

$$\mathbf{A}x + d = x , \tag{4}$$

where $\mathbf{A} = [a_{ij}]$, $x = [x_i]$ and $d = [d_i]$. The matrix **A** is called the technological (or input-output or consumption) matrix of the economy. Solving for x we obtain

$$x = (\mathbf{I} - \mathbf{A})^{-1} d \ , \qquad (5)$$

where $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ is called the Leontief inverse matrix. If the technological matrix **A** is known and does not change over the projection period, we can use equation (5) to predict the vector of total output x and, for example, new inter-industry transactions x_{ij} resulting from changes in the final demand vector d.

Over a long time span, the technical coefficients (equation (2)) will be affected by four kinds of changes: changes in the relative prices of inputs, appearance of new industries, changes in the product mix of a particular industry (Davis et al., 1977) and technological change (Miernyk, 1965). The early input-output-studies demonstrated empirically the change of technical coefficients (Leontief, 1953; Carter, 1967) and suggested methods for updating the technical coefficients without having to rely on time- and resource-intensive survey-based aggregation of the input-output tables. Among the most prominent and widely applied updating methods are the RAS method (Bates and Bacharach, 1963) and linear programming (Matuszewski et al., 1964). RAS has been shown to be superior at both regional and national level (Davis et al., 1977). A disadvantage of both methods is that they require a lot of input data: 1) the coefficient matrix **A** for a base year, 2) vector of gross outputs of each industry for the target year, 3) vector of intermediate outputs and 4) vector of intermediate inputs. In addition, they are purely mechanical routines not allowing for informed judgment regarding changes in the coefficients of interest. However, more recent evidence implies that judgment-based methods like Delphi could provide reliable and valid information for input-output analysis (Landeta et al., 2008).

The early updating methods also present the results as point estimates, failing to take into account the probabilistic nature of the input coefficients (West, 1986). Buckley (1989) introduced a method to incorporate fuzzy numbers in input-output analysis, and theoretically derived the conditions for the fuzzy model to exist. The advantage of this method over the more traditional approaches to updating the technical coefficients is that the vectors of final demand and sums of intermediate outputs and inputs do not need to be known exactly. More recently, Beynon et al. (2005) and Beynon and Munday (2006) further developed the fuzzy input-output analysis of Buckley (1989). Sevastjanov and Dymova (2009), Mattila and Luukka (2009), Luukka and Mattila (2009) as well as Dymova et al. (2013), also examined fuzzy methods in Leontief input-output analysis.

The underlying idea in this paper is that when solving an input-output model we assume both final demand d and the technological matrix $\mathbf{A}$ to be fuzzy. This is based on the assumption that, in both demand vector and technical coefficients, there is a certain level of uncertainty. Hence, when solving the total output it will inherit this uncertainty as well. Here, we approach this problem with the tools mainly introduced in (Mattila and Luukka, 2009) and (Luukka and Mattila, 2009) coming from fuzzy logic.

We consider the following fuzzy linear system:

$$\begin{matrix} a_{11}x_1 + & a_{12}x_2 + & \cdots & + a_{1n}x_n & = b_1 \\ a_{21}x_1 + & a_{22}x_2 + & \cdots & + a_{2n}x_n & = b_2 \\ \vdots & & & & \\ a_{n1}x_1 + & a_{n2}x_2 + & \cdots & + a_{nn}x_n & = b_n \end{matrix}, \tag{6}$$

or in matrix format **A**x = b, where **A =** [a_{ij}] and b = [b_i] are considered to be fuzzy numbers instead of crisp values. The same applies of course also for (**I-A**)x = d.

The Jacobi method for solving this linear system is

$$x_i^{k+1} = \frac{1}{a_{ii}}\left(b_i - \sum_{\substack{j=1 \\ j\neq i}}^{n} a_{ij}x_j^k \right) \quad . \tag{7}$$

It is an iterative algorithm for determining the solutions of the system of linear equations. In our approach, the addition, subtraction, multiplication and division operations are coming from fuzzy logic (Dubois and Prade, 1980). The idea for solving fuzzy linear systems in this manner is introduced in (Mattila and Luukka, 2009) and (Luukka and Mattila, 2009) for the Gauss-Seidel and the successive over relaxation (SOR) algorithm. Here we use the Jacobi method because of its nice convergence properties.

We use the left-right (LR) -type fuzzy numbers, which can be written as

$$\mu_A(x) = \begin{cases} L((M-x)/l) & if \quad x \le M \\ R((x-M)/r) & if \quad x \ge M \end{cases} \tag{8}$$

for $l > 0$ and $r > 0$. For LR-type function, we use $L(x) = R(x) = max\ [1-x, 0]$, so that we are basically dealing with triangle type fuzzy numbers. LR-type fuzzy numbers can be expressed using the modal value M, the left support length l, and the right support length r as $A = (M, l, r)$.

In order to apply the Jacobi method, we need the extended sum, difference, product and division for fuzzy numbers. The extended sum is

$$A_1 + A_2 = (M_1 + M_2, l_1 + l_2, r_1 + r_2), \quad (9)$$

and the extended difference is

$$A_1 - A_2 = (M_1 - M_2, l_1 + r_2, r_1 + l_2). \quad (10)$$

The extended product is:

For $M_1 > 0$ and $M_2 > 0$

$$A_1 \cdot A_2 = (M_1 M_2, M_1 l_2 + M_2 l_1 - l_1 l_2, M_1 r_2 + M_2 r_1 + r_1 r_2), \quad (11)$$

for $M_1 < 0\, and\, M_2 > 0$

$$A_1 \cdot A_2 = (M_1 M_2, M_2 l_1 - M_1 r_2 + l_1 r_2, M_2 r_1 - M_1 l_2 - r_1 l_2), \quad (12)$$

for $M_1 > 0$ and $M_2 < 0$

$$A_1 \cdot A_2 = (M_1 M_2, M_1 l_2 - M_2 r_1 + l_2 r_1, M_1 r_2 - M_2 l_1 - r_2 l_1), \tag{13}$$

and for $M_1 < 0$ and $M_2 < 0$

$$A_1 \cdot A_2 = (M_1 M_2, -M_2 r_1 - M_1 r_2 - r_1 l_2, -M_2 l_1 - M_1 l_2 + l_1 r_2). \tag{14}$$

See more about these product rules in (Dubois and Prade, 1980).

The extended division for $M_1 > 0$ and $M_2 > 0$ is

$$\frac{A_1}{A_2} = \left(\frac{M_1}{M_2}, \frac{r_2 M_1 + l_1 M_2}{M_2^2}, \frac{l_2 M_1 + r_1 M_2}{M_2^2} \right). \tag{15}$$

Similarly, other formulas for divisions can be derived when M_1 and/or M_2 are negative. For more about this, see (Dubois and Prade, 1980).

Although updating technical coefficients by using fuzzy numbers is not a novel idea and various fuzzy techniques have been applied to Leontief input-output models, it appears that empirical studies with real data have not yet been reported in the academic literature. Also, reporting the predictive accuracy of fuzzy Leontief input-output applications is rare. This paper attempts to narrow the research gap by applying fuzzy input-output analysis to OECD's 2005 input-output tables to predict Finland's five sector input-output structure in 2010. The predictive accuracy of our method is examined by forecasting Finland's 2010 figures based on OECD's 1995 and 2000 input-output data as well.

4. Empirical results

In this section, we apply comparative analysis of inter-industry purchases and sales as well as the fuzzy input-output model presented in section 3. We first describe the inter-industry linkages between PPI and the other industries in Brazil, Finland and the United States. We are especially interested in the potential differences between the countries and the changes in the technical coefficients and inter-industry linkages between 1995 and 2005. Finally, we predict the structure of inputs and outputs of the PPI, and other industries closely related to it, in Finland in 2010.

4.1. Data collection

The input-output tables (Total tables) for Brazil, Finland and the United States were collected from the OECD's Structural Analysis Database (OECD, 2013). The database includes national input-output tables for three years (1995, 2000 and 2005) and 48 countries in current national currency and US dollars. Input-output tables from all the available years were used in this study. The volumes of purchases and sales were converted to constant 2005 US dollars by deflating with the GDP deflator before the analyses.

OECD's input-output tables include 37 industries. Unfortunately, the PPI is aggregated with the printing and publishing industries in them. We thus examined some more disaggregated input-output tables provided by Statistics Finland and Instituto Brasileiro de Geografia e

Estatística. As a result, we were able to limit our analyses to the industries that are more likely linked with the PPI than printing and publishing industry.

4.2. Results and discussion

4.2.1. Inter-industry linkages in Brazil, Finland and the United States

Tables 2 - 4 show the volume of purchases from other industries by the pulp, paper, printing and publishing industry in Brazil, Finland and the United States. Correspondingly, tables 5 - 7 show the volume of sales by the pulp, paper, printing and publishing industry to other industries. The ten largest sellers and purchasers are depicted. The technical coefficients (in Tables 2 to 4), non-industrial inputs (in Tables 2 to 4), the final demand sector (in Tables 5 to 7) and total gross output are shown as well. Non-industrial inputs include gross operating surplus (GOS), compensation of employees (LABR) and net taxes on production (TAXES). The final demand sector incorporates final consumption by households, non-profit organizations and government (HNG), gross fixed capital formation, i.e., investments (GFCF), changes in inventories (CINV), exports (EXPORT) and imports (IMPORT). All monetary values are expressed in 2005 US dollars. This comparative analysis focuses on the linkages between the PPI and other industries, while the linkages more likely related to the printing and publishing industry are mainly ignored.

[Table 2 near here]

[Table 3 near here]

[Table 4 near here]

There are many differences but also some similarities across the three countries. First of all, it is evident that the technical coefficients have changed between 1995 and 2005 in all three countries. Also, technical coefficients differ between the countries. The PPI is by far the largest purchaser of its own products in all of the countries. This is due to pulp that is bought as an input to the paper and board production processes. In addition to the volume of paper and board production, the volume of intra-industry purchases depends on pulp prices and the availability and price of recovered paper, which is also an important raw material in paper and board production (see, e.g., Arminen et al., 2013).

Large amounts of chemicals are used in pulp and paper manufacturing. Chemicals and chemical products industry is the second largest seller in Brazil and among the largest ones in Finland and in the United States. The PPI's purchases from the chemical industry almost doubled in Brazil between 1995 and 2005. This is consistent with the rapidly increased production of wood pulp from eucalyptus trees (see, e.g., Hujala et al., 2013). Instead, in Finland purchases from the chemical industry increased between 1995 and 2005 and decreased between 2000 and 2005. In the United States, purchases from the chemical industry have declined since 1995. Thus, it seems that the volume of the purchases from the chemical industry is linked to the upwards and downwards of the PPI. Also, the direct purchases from forestry and transport industries seem to follow the volumes of pulp and paper production. In contrast to Brazil and Finland, forestry is not among the top ten sellers in the United States and is thus not included in Table 4.

The wholesale and retail trade industry includes, among others, the wholesale of waste and scrap, such as waste paper. The volume of purchases from the wholesale industry declined in all of the countries between 2000 and 2005. However, a significant part of the purchases from the wholesale and retail is linked to the printing and publishing industry, so that this result is somewhat uncertain.

The volume of purchases from electricity, gas and water supply industry increased in Brazil between 1995 and 2005. This is consistent with the mounting paper and board production. On the contrary, in Finland, the purchases from the electricity industry decreased between 1995 and 2000 and increased between 2000 and 2005. The opposite trend between electricity purchases and paper and board production in Finland may be a consequence of changes in electricity prices. According to International Energy Agency's electricity price database, Finnish electricity end-user prices decreased between 1995 and 2000 and increased between 2000 and 2005. In the United States, electricity industry is not among the top ten sellers.

Purchases from machinery and equipment industry declined in Brazil between 2000 and 2005. The technical coefficients a_{ij} of machinery and equipment industry declined as well. The machinery and equipment industry includes, among others, manufacturing of machinery especially designed for the PPI as well as manufacturing of more general purpose machinery. It thus seems that the number of new pulp and paper mills and/or machines decreased between 2000 and 2005. Instead, in Finland, both purchases and technical coefficients increased between 1995 and 2005.

As shown in Table 4, in the United States R&D was the third largest seller to the pulp, paper printing and publishing industry in 2000 and 2005. Thus, it seems that, either the PPI has reacted to declining markets by increasing its R&D investments, or R&D industry is linked with printing and publishing industry, not with the PPI. In Finland, the importance of R&D increased between 1995 and 2005 as well, although it is nowhere near the top ten sellers.

[Table 5 near here]

[Table 6 near here]

[Table 7 near here]

Most of the industries in tables 5-7 are more closely linked with printing and publishing than the PPI. According to our knowledge, only food industry, chemical industry, real estate activities, as well as wholesale in Brazil, are important buyers of PPI products. In Finland and in the United States, there are no significant changes in the sales from pulp, paper, printing and publishing industry to these industries measured as the percentage of total gross output. The same applies to chemical industry in Brazil. Instead, the role of food industry and wholesale has declined in Brazil between 2000 and 2005.

In Brazil and the United States, the total intermediate consumption (TIC) accounted for about 70%, and private and public consumption (HNG) for about 20 % of the total output in 2005 indicating that the domestic consumption is the main driver of the PPI's gross output (although the importance of exports has increased in Brazil). In Finland, the PPI is highly dependent on exports, which accounted for 50% of the gross output in 2005. Thus, the main driver is foreign demand (Europe's demand for paper and board, to be precise, since paper and board is consumed near the production (e.g. Valtonen, 2008).

4.2.2. Finland's input-output structure in 2010

Based on the analysis above, we adopted pulp and paper exports and imports as well as forestry imports as the major driving forces of changes in transactions between the PPI and other industries in Finland. We proposed two final demand scenarios, A (pessimistic) and B (optimistic), based on these driving forces and forecasted Finland's input-output structure in 2010.

We limited our analysis to five industry sectors: agriculture, hunting, forestry and fishing (forestry); wood and products of wood and cork (wood); pulp, paper, paper products, printing and publishing (pulp, paper), electricity, gas and water supply (electricity) and other industries (other). Table 8 presents Finland's aggregated five sector input-output tables in 1995, 2000 and 2005.

[Table 8 near here]

As shown in Table 8, purchases from the forestry and wood products industries by the electricity industry increased rapidly between 1995 and 2005. Thus, more and more wood material is used in energy production in Finland. In the future, the energy use of wood fiber is likely to continue rising if demand for biofuels grows vastly (see, e.g., Alcamo et al., 2005).

4.2.2.1. Final demand scenarios

At first, it was necessary to determine estimates of the final demand components (private and public consumption, investments, changes in inventories, exports and imports). We based our estimations on various data sources, such as Finnish Statistical Yearbook of Forestry by Finnish Forest Research Institute, ForesSTAT database by FAO, Preliminary Energy Statistics 2009 by Statistics Finland and Country Statistics database by MarketLine. Estimates are shown in Table 9.

[Table 9 near here]

Scenarios for final demand were then calculated based on Table 9 by subtracting imports from the sum of HNG, GFCF, CHINV and exports. Final demand scenarios are presented in Table 10.

[Table 10 near here]

4.2.2.2. Predictions of total output and inter-industry transactions for 2010

As shown in section 4.2.1, the technical coefficients of the PPI are not constant but change over time. Thus, we applied the fuzzy input-output model presented in Section 3 to predict total outputs and inter-industry transactions in 2010.We used fuzzy technical coefficients a_{ij} and fuzzy demand vector d, during the analyses. The uncertainty of a_{ij} and d was assumed to be 4 %. This basically means that, for example, if we have a crisp value $y = 100$, our fuzzy value is $y = [100\ 0.04*100\ 0.04*100] = [100\ 4\ 4]$. Thus, the left-hand corner value of the fuzzy triangle is *96*, the modal value is *100* and the right-hand corner value is *104*.

Fuzzy total outputs for the final demand vectors A and B are presented in Table 11 and Figure 1. Fuzzy inter industry transactions that would be needed to sustain the projected levels of final demand are presented in Table 12.

[Table 11 near here]

[Figure 1 near here]

[Table 10 near here]

As shown in Table 11 and Figure 1, total output of industries increased between 2005 and 2010 except for the PPI in scenario A. The fuzzy triangles of total output of forestry are almost identical between scenarios A and B, and the triangles of wood products industry, electricity industry and other industries overlap as well. It thus seems that drastic changes in PPI exports and forestry imports do not cause large changes in output of other industries

In scenario A, the PPI's purchases from other industries decreased by approximately 10% compared to the year 2005, and, respectively, increased by 10% in scenario B. Hence, changes in final demand are almost fully transferred to direct purchases from other industries. Intra-industry purchases of forestry increased in both of the scenarios compared to the year 2005 indicating that Russian roundwood is replaced by domestic roundwood. Sales from forestry and wood products industry to electricity industry are approximately the same in scenarios A and B. Thus, it seems that there is no competition for wood fiber between energy use and pulp and paper manufacturing at this point. Instead, pulp and paper production complements energy use, since, for example, mill residues and harvesting residues are biomass sources for energy production (Nurmi, 2007). According to Raunikar et al. (2010), industrial roundwood will not began to be used for energy production until the real price of fuelwood will converge towards the industrial roundwood as a result of high demand for biofuels.

4.2.2.3. Prediction accuracy

In order to evaluate the accuracy of our projections, we estimated year 2005 total outputs by using 1995 and 2000 technical coefficients a_{ij} and the real 2005 final demand vector. We compared the results with observed 2005 outputs added with 4% uncertainty. Observed and predicted fuzzy triangles of total output are presented in Appendix. As shown, observed and predicted triangles overlap pretty nicely. Thus, it seems that in this study, 4 % uncertainty in technical coefficients was enough to cover their change over time.

5. Conclusions

In this paper, we first identified the most important inter-industry linkages between the PPI and other industries in Brazil, Finland and the United States. All three countries are important players in the global pulp and/or paper markets. However, they are at different stages of economic development. Brazil is a newcomer in the global pulp markets but has increased its importance as a global pulp producer considerably since the late-1990s. In contrast, Finland and the United States are old paper and pulp producers and exporters and have suffered from stagnating markets in Western Europe and North America.

Our focus was on the differences in the inter-industry relationships between the countries as well as on the changes in the linkages between industries over time. According to our results, there are significant differences in the inter-industry linkages between Brazil, Finland and the United States, and also over time. The structure of direct purchases from other industries by the PPI has clearly changed between the mid-1990s and mid-2000. Instead, the sales from the PPI to other industries have remained relatively constant over time. It thus appears that the megatrends shaping PPI's operating environment have altered the technical coefficients, i.e. the "recipe", of the PPI in all three countries investigated, although the aggregation of the PPI with the printing and publishing industry slightly disturbed our interpretations (especially with the United States). Overall, globalization seems to have been the most significant trend behind the changes in the "recipe". The impact of global changes in pulp and paper markets on inter-industry linkages was seen in all of the sample countries. Instead, technological development and environmental awareness seem to have had less prominent role.

The other objective of this paper was to apply fuzzy linear systems in predicting Finland's input-output structure for the PPI and four other industries – forestry, wood, electricity and other – in 2010. We proposed two final demand scenarios: a pessimistic one and an optimistic one, and used fuzzy technical coefficients based on 2005 figures as well as fuzzy final demand vector in our analysis. Rather surprisingly, pessimistic and optimistic scenarios resulted in drastically different outputs of the PPI but with the other industries the differences in outputs between scenarios were barely notable. Thus, our results seem to indicate that the role of the PPI in the total output of the other industries is relatively small in Finland.

Due to structural changes in the input and output markets of PPI it is particularly important to take into account possible uncertainties and perform sensitivity analysis when forecasting forest product sector development. Fuzzy input-output analysis with 4% uncertainty in technical coefficients and final demand vector was found to be a useful and fairly accurate forecast method in this study. However, more analyses with real data as well as comparisons with traditional methods for updating technical coefficients are needed prior to drawing further conclusions.

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Appendix Estimates for year 2005 based on 1995 and 2000 data

[Figure A1 near here]

[Figure A2 near here]

Figures

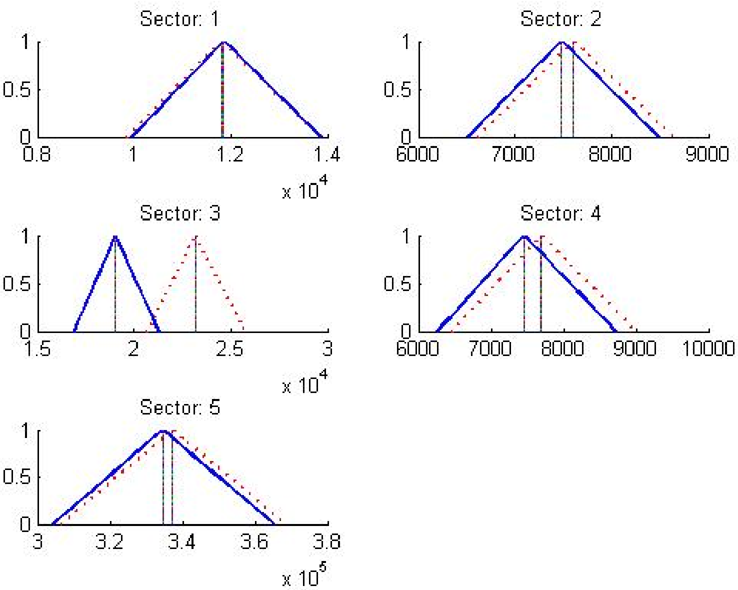

Figure 1 Predicted total output in 2010 for the final demand vector A (solid blue line) and for the final demand vector B (dashed red line).

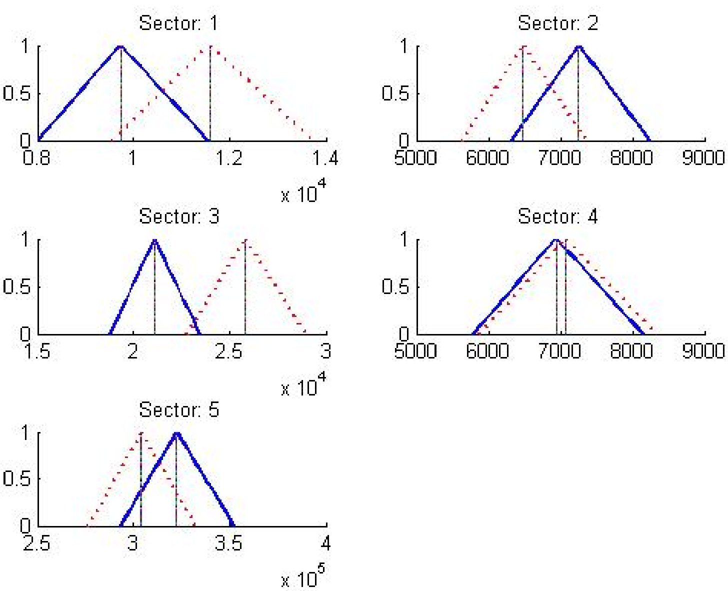

Figure A1 Observed (solid blue line) and predicted (dashed red line) total output for 2005 (year 1995 fuzzy a_{ij}).

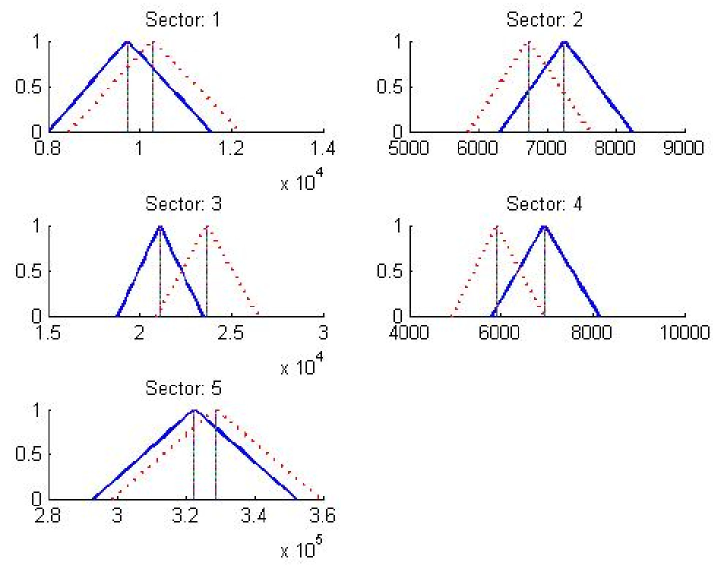

Figure A2 Observed (solid line) and predicted (dashed line) total output for 2005 (year 2000 fuzzy a_{ij}).

Tables

Table 1 An input-output table

		Industry inputs			Final demands					
		Industry 1	Industry 2	Industry n	HHFC	CHINV	EXP	…	Total final demand	Total gross output
Industry outputs	Industry 1	x_{11}	x_{12}	…	$HHFC_1$	…	…	…	d_1	x_1
	Industry 2	x_{21}	…	…	$HHFC_2$	…	…	…	d_2	x_2
	Industry n	x_{n1}	…	x_{ij}	$HHFC_n$	…	…	…	d_n	x_n
	GOS	GOS_1	…	GOS_j						
	LABR	$LABR_1$	…	$LABR_j$						
	TAXES	$TAXES_1$	…	$TAXES_j$						
	Total input	x_1	x_2	x_n						

Table 2 Technical coefficients, a_{ij}, and the volume of purchases from other industries by the pulp, paper, printing and publishing industry in Brazil.

1995	Million USD	a_{ij}	2000	Million USD	a_{ij}	2005	Million USD	a_{ij}
Pulp, paper etc	5133	0.272	Pulp, paper etc	6837	0.255	Pulp, paper etc	5640	0.186
Chemicals	1341	0.071	Chemicals	1688	0.063	Chemicals	2463	0.081
Wholesale	1116	0.059	Wholesale	1581	0.059	Forestry	1784	0.059
Public admin.	1009	0.053	Public admin.	816	0.030	Electricity	1163	0.038
Finance	656	0.035	Electricity	772	0.029	Wholesale	1158	0.038
Electricity	488	0.026	Finance	717	0.027	Other business	1062	0.035
Forestry	465	0.025	Petroleum	526	0.020	Transport	954	0.031
Machinery	395	0.021	Forestry	505	0.019	Rubber	728	0.024
Transport	325	0.017	Machinery	474	0.018	Finance	671	0.022
Petroleum	319	0.017	Telecomm.	441	0.016	Machinery	350	0.012
TIDPP	13032	0.691	TIDPP	17563	0.654	TIDPP	19077	0.629
GOS	2552	0.135	GOS	4835	0.180	GOS	5778	0.191
LABR	2691	0.143	LABR	3302	0.123	LABR	5166	0.170
TAXES	587	0.031	TAXES	1149	0.043	TAXES	286	0.009
Gross output	18862	1.000	Gross output	26848	1.000	Gross output	30307	1.000

Table 3 Technical coefficients, a_{ij}, and the volume of purchases from other industries by the pulp, paper, printing and publishing industry in Finland.

1995	Million USD	a_{ij}	2000	Million USD	a_{ij}	2005	Million USD	a_{ij}
Pulp, paper etc	6289	0.269	Pulp, paper etc	5765	0.221	Pulp, paper etc	4399	0.209
Chemicals	1438	0.062	Forestry	1765	0.068	Transport	1494	0.071
Transport	1242	0.053	Transport	1657	0.063	Forestry	1448	0.069
Electricity	1158	0.050	Chemicals	1475	0.056	Chemicals	1355	0.064
Other business	1115	0.048	Other business	1033	0.040	Electricity	964	0.046
Forestry	1096	0.047	Electricity	941	0.036	Other business	818	0.039
Wood	923	0.039	Wholesale	809	0.031	Wholesale	641	0.030
Mining	320	0.014	Wood	556	0.021	Machinery	532	0.025
Finance	277	0.012	Machinery	531	0.020	Wood	403	0.019
Machinery	265	0.011	Mining	430	0.016	Mining	390	0.019
TIDPP	15556	0.666	TIDPP	17190	0.658	TIDPP	14361	0.681
GOS	4422	0.189	GOS	5183	0.198	GOS	3089	0.147
LABR	3449	0.148	LABR	3753	0.144	LABR	3646	0.173
TAXES	-54	-0.002	TAXES	-10	0.000	TAXES	-11	-0.001
Gross output	23373	1.000	Gross output	26116	1.000	Gross output	21085	1.000

Table 4 Technical coefficients, a_{ij}, and the volume of purchases from other industries by the pulp, paper, printing and publishing industry in the United States.

1995	Million USD	a_{ij}	2000	Million USD	a_{ij}	2005	Million USD	a_{ij}
Pulp, paper etc	121 068	0.231	Pulp, paper etc	107 733	0.188	Pulp, paper etc	84 367	0.161
Wholesale	25 618	0.049	Wholesale	26 674	0.046	Wholesale	24 999	0.048
Chemicals	17 276	0.033	R&D	20 832	0.036	R&D	20 607	0.039
Other business	16 543	0.032	Other comm.	19 532	0.034	Other comm.	17 093	0.033
Transport	15 189	0.029	Transport	16 570	0.029	Transport	16 157	0.031
Wood	11 216	0.021	Other business	15 331	0.027	Chemicals	13 236	0.025
Real estate	9 044	0.017	Chemicals	14 686	0.026	Other business	13 147	0.025
Electricity	8 633	0.016	Finance	11 851	0.021	Finance	10 279	0.020
Rubber	7 863	0.015	Office mach.	10 390	0.018	Real estate	8 478	0.016
Construction	5 715	0.011	Telecomm.	8 372	0.015	Telecomm.	7 849	0.015
TIDPP	28 0571	0.535	TIDPP	324 087	0.564	TIDPP	283 440	0.542
GOS	78 989	0.151	GOS	81 021	0.141	GOS	97 257	0.186
LABR	160 894	0.307	LABR	165 035	0.287	LABR	137 888	0.263
TAXES	4 062	0.008	TAXES	4 167	0.007	TAXES	4 727	0.009
Gross output	524 515	1.000	Gross output	574 311	1.000	Gross output	52 3312	1.000

Table 5 The volume of sales from the pulp, paper, printing and publishing industry to other industries in Brazil.

1995	Million USD	% of gross output	2000	Million USD	% of gross output	2005	Million USD	% of gross output
Pulp, paper etc	5133	27 %	Pulp, paper etc	6837	25 %	Pulp, paper etc	5640	19 %
Public admin.	2143	11 %	Other business	2448	9 %	Other business	3832	13 %
Other business	1448	8 %	Public admin.	2218	8 %	Finance	1785	6 %
Wholesale	1334	7 %	Wholesale	1922	7 %	Food	1185	4 %
Food	1281	7 %	Food	1793	7 %	Telecomm.	1090	4 %
Chemicals	484	3 %	Chemicals	715	3 %	Wholesale	1007	3 %
Other comm.	325	2 %	Other comm.	547	2 %	Chemicals	982	3 %
Finance	313	2 %	Computer	504	2 %	Other comm.	844	3 %
Textiles	304	2 %	Textiles	383	1 %	Public admin.	668	2 %
Computer	303	2 %	Other non-met.	358	1 %	Health	589	2 %
TIC	15485	82 %	TIC	21493	80 %	TIC	21376	71 %
HNG	2469	13 %	HNG	4155	15 %	HNG	6318	21 %
GFCF	49	0 %	GFCF	44	0 %	GFCF	36	0 %
CINV	-45	0 %	CINV	134	0 %	CINV	68	0 %
EXPORT	2026	11 %	EXPORT	2399	9 %	EXPORT	3704	12 %
IMPORT	1122	6 %	IMPORT	1377	5 %	IMPORT	1194	4 %
Gross output	18862		Gross output	26848		Gross output	30307	

Table 6 The volume of sales from the pulp, paper, printing and publishing industry to other industries in Finland.

1995	Million USD	% of gross output	2000	Million USD	% of gross output	2005	Million USD	% of gross output
Pulp, paper etc	6289	27 %	Pulp, paper etc	5765	22 %	Pulp, paper etc	4399	21 %
Wholesale	907	4 %	Wholesale	964	4 %	Wholesale	1058	5 %
Food	448	2 %	Other comm.	593	2 %	ICT equip.	573	3 %
Other comm.	425	2 %	ICT equip.	534	2 %	Other comm.	530	3 %
Other business	362	2 %	Other business	467	2 %	Other business	504	2 %
Chemicals	306	1 %	Food	465	2 %	Food	353	2 %
Hotels	299	1 %	Real estate	313	1 %	Real estate	249	1 %
Public admin.	251	1 %	Chemicals	279	1 %	Public admin.	211	1 %
Transport	250	1 %	Public admin.	237	1 %	Chemicals	203	1 %
Real estate	185	1 %	Machinery	220	1 %	Machinery	190	1 %
TIC	11494	49 %	TIC	11949	46 %	TIC	9931	47 %
HNG	1276	5 %	HNG	1306	5 %	HNG	1678	8 %
GFCF	6	0 %	GFCF	35	0 %	GFCF	23	0 %
CINV	137	1 %	CINV	98	0 %	CINV	279	1 %
EXPORT	11345	49 %	EXPORT	13885	53 %	EXPORT	10470	50 %
IMPORT	886	4 %	IMPORT	1158	4 %	IMPORT	1295	6 %
Gross output	23373		Gross output	26116		Gross output	21085	

Table 7 The volume of sales from the pulp, paper, printing and publishing industry to other industries in the United States.

1995	Million USD	% of gross output	2000	Million USD	% of gross output	2005	Million USD	% of gross output
Pulp, paper etc	121068	23 %	Pulp, paper etc	107733	19 %	Pulp, paper etc	84367	16 %
Other business	94443	18 %	Public admin.	33690	6 %	Public admin.	36576	7 %
Wholesale	41928	8 %	Other comm.	29175	5 %	Other comm.	26619	5 %
Food	23155	4 %	Wholesale	28367	5 %	Wholesale	24286	5 %
Health	21233	4 %	Food	24591	4 %	Food	22352	4 %
Finance	16643	3 %	R&D	21981	4 %	R&D	22149	4 %
Other comm.	15056	3 %	Health	18603	3 %	Health	16475	3 %
Education	13967	3 %	Office mach.	17186	3 %	Office mach.	11744	2 %
Construction	13084	2 %	Finance	13055	2 %	Finance	9837	2 %
Telecomm.	10712	2 %	Chemicals	11068	2 %	Chemicals	9778	2 %
TIC	448137	85 %	TIC	401162	70 %	TIC	349721	67 %
HNG	72610	14 %	HNG	93738	16 %	HNG	92546	18 %
GFCF	2830	1 %	GFCF	72817	13 %	GFCF	79949	15 %
CINV	1854	0 %	CINV	3484	1 %	CINV	1564	0 %
EXPORT	23754	5 %	EXPORT	31967	6 %	EXPORT	30508	6 %
IMPORT	24670	5 %	IMPORT	28857	5 %	IMPORT	30975	6 %
Gross output	524515		Gross output	574311		Gross output	523312	

Table 8 Five sector input-output tables of Finland in 1995, 2000 and 2005.

1995	Forestry	Wood	Pulp, paper	Electr.	Other	HNG	GFCF	CHINV	EXPORT	IMPORT	FD	Total output
Forestry	1802	1864	1096	1	3665	1274	277	426	530	986	1521	9949
Wood	13	473	923	31	1275	52	1	24	3054	603	2529	5243
Pulp, paper	116	97	6289	105	4887	1276	6	137	11345	886	11879	23373
Electricity	181	126	1158	193	3089	1164	69	0	27	206	1055	5803
Other	2434	1127	5936	2020	86309	84595	20880	1339	33709	35576	104947	202772

2000	Forestry	Wood	Pulp, paper	Electr.	Other	HNG	GFCF	CHINV	EXPORT	IMPORT	FD	Total output
Forestry	2027	2174	1765	13	3446	1252	142	143	639	1472	704	10129
Wood	6	827	556	106	2034	33	8	21	3880	353	3589	7120
Pulp, paper	52	132	5765	107	5893	1306	35	98	13885	1158	14167	26116
Electricity	171	126	941	82	3473	761	24	0	17	105	697	5491
Other	2374	2125	8042	2496	129063	100559	31390	1167	53354	53040	133431	277531

2005	Forestry	Wood	Pulp, paper	Electr.	Other	HNG	GFCF	CHINV	EXPORT	IMPORT	FD	Total output
Forestry	2184	2171	1448	42	3412	1404	235	125	598	1894	469	9726
Wood	12	1076	403	165	2687	62	16	- 33	3443	576	2912	7255
Pulp, paper	24	80	4399	71	5356	1678	23	279	10470	1295	11154	21085
Electricity	101	174	964	181	4961	1053	32	3	40	572	556	6937
Other	2436	2051	7041	2622	146920	123927	34082	2926	65788	65273	161450	322521

Table 9 Estimates of each component of final demand compared to the year 2005.

	Component of final demand				
Industry	HNG	GFCF	CHINV	Exports	Imports
Forestry	xx	x	x	xx	A: Are assumed to decrease by 80% (50% decrease in imports compared to the year 2009) B: B: Are assumed to decrease by 59% (imports remain at the 2009 level)
Wood	xx	x	x	xx	xx
Pulp, paper	xx	x	x	A: Are assumed to decrease by 15% (demand for Finnish paper and pulp collapses compared to the year 2008 and prices remain at low levels) B: Are assumed to increase by 15% (demand increases slightly compared to the year 2008 (environmental catastrophes e.g. in Chile and supply uncertainty))	A: Are assumed to increase by 25% (imports increased by 15% between 2005 and 2008) B: Are assumed to increase by 20% (more roundwood is imported compared to the scenario A)
Electricity	A&B: Is assumed to increase by 35% (households electricity prices increased by 25-45% between 2005 and 2009)	x	x	A& B: Are assumed to increase by 300% (exports nearly trebled between 2005 and 2009)	A&B: Are assumed to increase by 10%
Other	xx	x	x	xx	xx

x indicates that the component is assumed to be the same as in 2005

xx indicates that the component is assumed to increase by 4 %, which is the expected GDP growth between 2005 and 2010

Table 10 2010 final demand scenarios for Finland.

Sector	Final demand 2010 A	Percent change	Final demand 2010 B	Percent change
1. Forestry	2064	340 %	1666	255 %
2. Wood	3029	4 %	3029	4 %
3. Pulp, paper.	9327	-16 %	12532	12 %
4. Electricity	947	70 %	947	70 %
5. Other	167908	4 %	167908	4 %

Table 11 Predicted total output in 2010 for the final demand vectors A and B. Fuzzy 2005 a_{ij} coefficients and fuzzy demand vectors were used.

Sector	X_A (million USD)	X_B (million USD)
1. Forestry	[11860 1890 2000]	[11800 1930 2040]
2. Wood	[7480 960 1 000]	[7610 990 1030]
3. Pulp, paper.	[19050 2160 2230]	[23160 2500 2570]
4. Electricity	[7460 1190 1260]	[7700 1240 1300]
5. Other	[334600 30150 30600]	[337320 30630 31100]

Table 12 Predicted inter-industry transactions for 2010.

Final demad scenario A
(million USD)

	1. Forestry	2. Wood	3. Pulp, paper	4. Electricity	5. Other
1.	[2660 510 570]	[2240 370 400]	[1310 200 210]	[50 10 10]	[3540 450 480]
2.	[20 0 0]	[1110 180 200]	[360 50 60]	[180 30 40]	[2790 350 380]
3.	[30 10 10]	[80 10 10]	[3970 590 640]	[80 10 20]	[5560 700 750]
4.	[120 20 30]	[180 30 30]	[870 130 140]	[190 40 40]	[5150 650 700]
5.	[2970 570 640]	[2120 350 380]	[6360 950 1030]	[2820 550 610]	[152420 19280 20590]

Final demad scenario B
(million USD)

	1. Forestry	2. Wood	3. Pulp, paper	4. Electricity	5. Other
1.	[2650 520 580]	[2280 370 410]	[1590 230 250]	[50 10 10]	[3570 450 480]
2.	[10 0 0]	[1130 190 200]	[440 60 70]	[180 40 40]	[2810 360 380]
3.	[30 10 10]	[80 10 20]	[4830 690 750]	[80 20 20]	[5600 710 760]
4.	[120 20 30]	[180 30 30]	[1060 150 160]	[200 40 40]	[5190 660 710]
5.	[2960 580 650]	[2150 350 390]	[7730 1110 1200]	[2910 570 630]	[153660 19540 20880]