Qualitative Input-Output Analysis of North Carolina Forest Sector Supply Chains

Nathan S. Gerber[1] and T. Eric McConnell[2]*

Abstract

Despite its contributions to the state economy, relatively little is known about North Carolina's forest-based economic network. In order to further understanding, qualitative input-output analysis was applied to determine the number of supply chains present within the state's forest industries. A 2014 input-output model of the North Carolina economy was constructed using the IMpact analysis for PLANning database. The inter-industry transactions table was first normalized by dividing the cells contained in each column by their respective sum. This illustrated the relative contribution each row industry provided to producing one dollar of each column industry's output, where the focus here was on the 29 sectors considered to be forest-based. Cells greater than or equal to $0.01 were re-coded as "1," else "0." This revealed direct purchases made by the forest sectors of measurable size, and sequentially raising this new binary matrix to higher powers illustrated the number of indirect connections between a forest sector and its upstream suppliers. While forest industries' direct links to other sectors numbered about 250, more than 15,000 total supply chains of three or fewer links were discovered. Forestry and Logging contained less supply chains than the manufacturing industries (Wood Products, Paper, and Wood Furniture) at each measured length. This is a first step to tracing the paths of transmission taken by the forest industries' multiplier effects through a regional economy. The benefits to understanding these pathways can include not only identifying where potential bottlenecks inhibiting forest-based growth may reside but also where economic assistance efforts could aid in tempering any negative effects associated with industry contraction.

Keywords: forestry and logging; input-output model; paper manufacturing; wood furniture manufacturing; wood products manufacturing

1.0 Introduction

Forestry in North Carolina contributes jobs and income to every county in the state through its linkages with more than 500 economic sectors (McConnell et al. 2016). The forest industry directly supported 70,300 jobs and $4.96 billion in value added to produce timber, wood products, paper and paper products, and furniture in 2013. Accounting for the industry's multiplier effects pushed total forest-based contributions to 144,800 jobs and $29.4 billion in output, which included $10.9 billion to the state's gross domestic product. For its size and importance to economies across the country (Dahal et al. 2015; Golden et al. 2015), there is little documented knowledge regarding forest industry supply chains beyond the recent identification of potential bottlenecks within Michigan's forest products export base (Cooke et al. 2015).

Many business-to-business transactions comprising an industry's supply chain network are simply direct purchases and intuitive. For instance, a sawmill acquires sawlogs for processing into lumber. But the timber harvester had to successfully bid for the landowner's timber, and the landowner in turn may have paid a professional forester to manage the property. This highlights a single supply chain with three links, but as many as six

Acknowledgements: We thank the anonymous reviewers for taking the time to review our manuscript and help us improve it.

1 Graduate student, Department of Sustainable Biomaterials, Virginia Tech University, Blacksburg, VA.

2 Assistant Professor, School of Agricultural Sciences and Forestry, Louisiana Tech University, Ruston, LA.

* Corresponding author: Email: temc@latech.edu

BioProducts Business 2(3), 2017, pp. 23-28. http://biobus.swst.org.
https://doi.org/10.22382/bpb-2017-003

individual chains of varying lengths are present in this straightforward example (Figure 1). The paths traced from the demanding sector (the sawmill in this example) to an upstream supplier become significantly more complex with each additional round of spending.

An economic input-output (I-O) table provides a mechanism for tracing an industry's purchases through the economy (Table 1). The I-O table quantifies transactions by how many dollars each sector makes (processes for sale to other sectors) and uses (purchases to produce its product). In the United States, business establishments are classified into sectors following the North American Industry Classification system (USDC Census Bureau 2016). For example, hardwood and softwood lumber producers are grouped collectively into the Sawmills sector.

The I-O table separates processing sectors by rows (i) and purchasing sectors by columns (j); every sector is considered to be both a processor and purchaser. Each

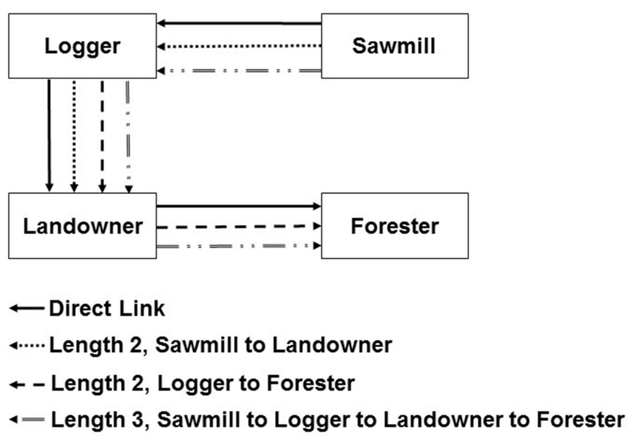

Figure 1. Hypothetical system of wood supply chains.

Table 1. Input-output table of a hypothetical three sector economy.

	Purchasing Sectors				
Processing Sectors	Agriculture and Forestry	Manufacturing	Services	Final Demand	Total Output
Agriculture and Forestry	8	4	4	20	36
Manufacturing	7	9	5	11	32
Services	4	2	4	24	34
Value Added	11	15	13		39
Imports	6	2	8		16
Total Outlay	36	32	34	55	157

cell of the table has a dual interpretation as either a sale (if reading across a row) or a purchase (if reading down a column). Summing each row quantifies an industry's output, or gross sales. This includes intermediate sales to other sectors along with those to final users. The total outlay of inputs, which are the column sums, includes local purchases from intermediate production sectors, value added, and institutions, as well as imports from outside the study region. The column and row sums must balance.

An industry's supply chain network more so resembles a web (Cooke et al. 2015) that is comprised of a number of poles (sectors) transmitting purchases along arc-like paths and occasional feedback loops across the economic system. Structural path analysis (SPA) maps and quantifies the flows present in an economic system. Defourny and Thorbecke (1984) published the seminal work on SPA using a social accounting matrix, which is an extension of the input-output table. The circular flows between industries, factors of production, and institutions were traced following injections at various stages using the South Korean economy as an example. SPA decomposes the multiplier matrix of total requirements[1] into various channels by which their influence to the system's total change can be quantified. A recent application of structural path analysis to the forest products industry occurred in Michigan, where the export base contributions of leading forest sectors were found to be highly dependent upon the production of locally sourced timber and wood products (Cooke et al. 2015). The concept has more recently expanded into other areas, including energy use and emissions (Matthews et al. 2015).

Highlighting the number of paths existing between a purchasing industry and supplying sector at each round of spending can be illustrated by qualitative I-O analysis (Aroche-Reyes 2003). This can provide a rapid assessment of important relationships underlying within a regional economy. Qualitative I-O analysis applies a binary approach to the matrix of industries' production requirements to determine the connections between

1 In matrix notation, $A^* = (I - A)^{-1}$, where A^* is the total requirements matrix, I is the matrix of initial requirements, and A is the matrix of fixed coefficient production functions. Each element of A^* describes the amount needed from sector i (row) as input to produce one dollar of output in sector j (column) to satisfy final demand. Summing the column elements for each industry j provides industry j's output multiplier.

sectors. Based upon a minimum size criterion set for inter-industry purchases, cells coded "0" are not connected, whereas a "1" means they share a connection. Graph theory can then be utilized to visually map a matrix's pathways. This method has been used to illustrate both economic (Ghosh et al. 1998) and environmental data (Seung 2014).

Our goal was to use qualitative I-O analysis to determine the number of inter-industry supply chains in North Carolina's forestry and forest products industries. This is a first step to gaining a better understanding of the state's forest-based network. A secondary goal was to compare the number of supply chains across industries at various transactional stages to determine if and where differences existed.

2.0 Methods

A North Carolina I-O model was constructed using IMPLAN's 2014 economic database of all 100 counties (IMPLAN LLC 2015). The IMPLAN system was created to detail the economic impacts of forest management activities occurring on federal forest lands to surrounding communities. The system is comprised of both a database and software that analyzes economic impacts generated within a predefined region in terms of dollars added into the economy and jobs produced. Data are obtained from various government sources, including the Bureau of economic Analysis, the US Census Bureau, and US Department of Agriculture, among many others. The current version of IMPLAN's I-O model is based on an economy containing 536 sectors.

North Carolina timber income accounts were customized using data collected by North Carolina State University Extension Forestry (Jeuck and Bardon 2015). The model was next aggregated from 536 sectors to 112 and reconstructed. Of the 112, 29 forest-based and 16 other agriculture, fishing, and hunting sectors remained completely disaggregated along with one non-wood furniture manufacturing sector. All others were aggregated to the 3-digit North American Industry Classification System (NAICS) classification (Table 2). The I-O table was exported to Excel, where the 112 x 112 Z-matrix of inter-industry activities was segregated for analysis.

Using the total outlays from the model, the Z-matrix was column-normalized to create the A-matrix of direct requirements, where

$$a_{ij} = \left(\frac{z_{ij}}{Z_{.j}}\right).$$

Each a_{ij} described the amount purchased from each row sector i to produce one dollar of column sector j's output. A filter size of 0.01 was established, where all direct suppliers with at least a \$0.01 contribution per dollar of sector output were highlighted. The approach originally taken was to calculate $a_{ij} \geq 1/n$ ($n = 112$) as a benchmark (Aroche-Reyes 2001), which was then rounded to a filter of $a_{ij} \geq 0.01$. This filter was applied to construct a W-matrix, which was a binary matrix consisting of 0s and 1s. Any cell value greater than or equal to the filter was coded as "1" else "0." The numbers of direct connections with suppliers for each forest-based sector were then summed.

Table 2. North Carolina forest-based industrial sectors.

Industry	IMPLAN Sectors (IMPLAN sector code)
Forestry and Logging (NAICS 113), and Support Activities for Forestry (NAICS 115)	Forestry, forest products, and timber tract production (15); Commercial logging (16); Support activities for forestry (19)
Wood Products Manufacturing (NAICS 321)	Sawmills (134); Wood preservation (135); Veneer and plywood manufacturing (136); Engineered wood member and truss manufacturing (137); Reconstituted wood product manufacturing (138); Wood windows and door manufacturing (139); Cut stock, resawing lumber, and planning (140); Other millwork, including flooring (141); Wood container and pallet manufacturing (142); Manufactured home manufacturing (143); Prefabricated wood building manufacturing (144); All other miscellaneous wood product manufacturing (145)
Paper Manufacturing (NAICS 322)	Pulp mills (146); Paper mills (147); Paperboard mills (148); Paperboard container manufacturing (149); Paper bag and coated and treated paper manufacturing (150); Stationery product manufacturing (151); Sanitary paper product manufacturing (152); All other converted paper product manufacturing (153)
Wood Furniture Manufacturing (NAICS 337)	Wood kitchen cabinet and countertop manufacturing (368); Upholstered household furniture manufacturing (369); Nonupholstered wood household furniture manufacturing (370); Institutional furniture manufacturing (372); Wood office furniture manufacturing (373); Custom architectural woodwork and millwork manufacturing (374)

The W-matrix was then sequentially multiplied by itself, which is an adaptation of the power series approximation of the total requirements matrix. Eight rounds will capture approximately 99% of a regional economy's total flows following an external change (Schaffer 1999). Here, higher powers of W illustrated the number of indirect connections between a forest sector and its upstream suppliers. The focus was on the number of connections of length 3 or less, because supply chains of greater length have been found to be of lesser economic consequence (Defourny and Thorbecke 1984; Dietzenbacher and Romero 2007). The numbers of chains connecting a row sector i with each forest sector j were summed following each round of multiplication.

Forest sector results for each round of expansion were collapsed into four broader industries for reporting: Forestry and Logging (n = 3 sectors), Wood Products Manufacturing (n = 12 sectors), Paper Manufacturing (n = 8 sectors), and Wood Furniture Manufacturing (n = 6 sectors). These aggregations served as class variables for performing a Kruskal-Wallis test of differences in the number of supply chains across industries at the alpha = 0.05 level using SAS 9.4 (2013).

3.0 Results

North Carolina's forest industries were found to contain a total of 15,691 supply chains (Table 3). Across all forest-based sectors 249 chains were direct links of length 1; 1,894 were of length 2; and 13,548 were of length 3. The overall number of Forestry and Logging supply chains was 584; Wood Products Manufacturing was 6,305; Paper Manufacturing was 4,917; and Wood Furniture Manufacturing was 3,885 respectively.

The four forest industry groups significantly differed with respect to the number of supply chains at each round of spending (Table 4). Given the much lower number of supply chains in Forestry and Logging relative to the other industries, we performed a second series of Kruskal-Wallis tests for only the three forest products manufacturing industries. Wood Products Manufacturing, Paper Manufacturing, and Wood Furniture Manufacturing did not significantly differ in the number of supply chains present across lengths (Table 4). While no significant differences were present between the forest products manufacturing industries, the results pointed to differences between the timber production sectors and at least one of the three forest products manufacturing industries.

4.0 Discussion

Converting inter-industry purchases to a binary system revealed more than 15,000 supply chains provided inputs to North Carolina's forest industries in 2014. The number of supply chains grew by an average factor of more than seven with each additional link of spending across all forest-based sectors. The industry with the lesser number of supply chains of direct length, length 2, and length 3 was Forestry and Logging. This was because the input-output model operates as a backward linked model, and Forestry and Logging is located at the upstream end of the forest industry production chain.

The W-matrix is easily interpreted by observing the column for the desired industry. Forest sector j in the column purchases input from row industry i, which likewise sells output to forest sector j. Higher powers of W (W^2 and W^3) reveal the number of supply chains beginning at forest sector j (the demanding sector) and ending at row sector i (the supplier), but the indirectly connected links themselves are not revealed. Supply chains of inter-

Table 3. North Carolina forest industry supply chains.

Industry	Number of Supply Chains			
	Length 1 (Direct)	Length 2	Length 3	Total
Forestry and Logging (n = 3)	12	76	496	584
Wood Products Manufacturing (n = 12)	100	764	5,441	6,305
Paper Manufacturing (n = 8)	80	593	4,244	4,917
Wood Furniture Manufacturing (n = 6)	57	461	3,367	3,885
All Forest Industries (n = 29)	249	1,894	13,548	15,691

Table 4. Kruskal-Wallis results comparing the number of supply chains present at each length across forest-based industries in North Carolina.

Industry	Supply Chain Lengths		
	Length 1 (Direct)	Length 2	Length 3
	p values		
All Forest Industries	0.010	0.008	0.001
Forest Products Manufacturing Industries	0.136	0.076	0.057

est can be mapped in this context, though, by referring back to the W-matrix to trace specific paths of 1s.

Significant differences in the number of supply chains between the four forest industries were found at each length. The Kruskal-Wallis test is nonparametric and can only be used to identify whether at least one significant difference exists between categories, not which categories are indeed significantly different. Visual inspection of the data suggested there was a significant difference in the number of supply chains between Forestry and Logging and at least one of the forest products manufacturing industries. Rerunning the Kruskal-Wallis tests exclusive of Forestry and Logging noted no significant differences. The fewer number of chains leading to Forestry and Logging overall was indicative of it being located at the upstream end of forest economic supply chains (Dietzenbacher et al. 2005).

The ripple effects forest industries have on other sectors in North Carolina's economy were underscored in this analysis. Given the number of links present in many forest sector supply chains, the effects are not necessarily one-step solutions to how a region reacts to industrial changes. Exogenous shocks experienced by one industry, such as an increase in lumber exports, spread backward through the economy to other industries both directly and indirectly connected to the sawmill sector. While the input-output model is to be considered as a snapshot in time, usually one year, sequential raising of the binary W matrix to higher powers highlighted the successive nature by which multiplier effects occur before a new equilibrium is reached.

Qualitative I-O analysis provides an efficient means of highlighting discernible linkages and the distance between sectors. How forestry and forest products in North Carolina might compare to other states' forest economies is currently unknown. The more regional nature of forest products industries and markets, e.g. Pacific Northwest, South, Appalachia, etc., might imply regional differences in structure, capacity, and performance as well. This is but one avenue of future research requiring further study.

The analyst's discretion governs exogenous filter size and will affect the number of chains revealed (Aroche-Reyes 2003). A filter too large will highlight only a minimal number of paths of the greatest magnitudes, while a filter too small can overstate the roles particular supply chains play in a region. Also, leakages, or monies leaving a region at each round of spending, dictate that a supply chain's overall influence lessens with its length (Schaffer 1999). The question(s) being asked will ultimately direct the research regarding transactional influences in a region.

This is a first step to quantitatively tracing the paths of transmission taken by forest industries' backward-linked multiplier effects, which can include not only identifying how other sectors contribute to forestry and forest products activities but also where potential bottlenecks inhibiting sector growth may reside. This could have particular policy implications in regions looking to the forest sector for development and/or expansion opportunities. For example, the impact a new sawmill might have in a region is relatively straight-forward to determine in terms of size (total sales of output, labor income paid to households, or value added provided to the region). But what is the order by which existing industries benefit by meeting these new demands? Are there potential factors present that might prevent this growth from reaching its potential?

As important, perhaps even more so, might be the opposite occurring – a mill closure. Multiplier effects not only describe the benefits of sector expansion, but they also illustrate the unfortunate effects of industry contraction. Understanding the paths negative effects might take could direct policymakers to particular key sectors that shared basic relationships with the affected facility. Economic assistance in this case could help lessen any fallout spilling over from the distressed forest sector.

5.0 References

Aroche-Reyes, F (2001) The question of identifying industrial complexes revisited: A qualitative perspective. Pages 280-296 *in* M. Lahr and E. Dietzenbacher, eds. Input-output analysis: Frontiers and extensions. Palgrave Macmillan, UK.

Aroche-Reyes, F (2003) A qualitative input-output method to find basic economic structures. Pap Reg Sci 82, 581-590.

Cooke, S, Kay, D, Alward, GS, Watson, P (2015) Identifying important sectors among Michigan's forest product sectors: Using I-O coefficients to measure comparative gross and base value added, competitive advantage, and structural path analysis. The Alward Institute for Collaborative Science, Huntersville, NC. 19 p.

Dahal, RP, Henderson, JE, Munn, IA (2015) Forest products industry size and multipliers in the US South. Forest Prod J 65(7/8):372-380.

Defourny, J, Thorbecke, E (1984) Structural path analysis and decomposition within a social accounting matrix. Econ J 94(373):111-136.

Dietzenbacher, E, Romero, I (2007) Production chains in an interregional framework: Identification by means of average

propagation lengths. Int Regional Sci Rev 30(4):362-383.
Dietzenbacher, E, Luna, IR, Bosma, NS (2005) Using average propagation lengths to identify production chains in the Andalusian economy. Estud Econ Apl 23(2):405-422.
Ghosh, S, Roy, J (1998) Qualitative input-output analysis of the Indian economic structure. Econ Syst Res 10(3):263-273.
Golden, JS, Handfield, RB, Daystar, J, McConnell, TE (2015) An economic impact analysis of the U.S. biobased products industry: A report to the Congress of the United States of America. A joint publication of the Duke Center for Sustainability & Commerce and the Supply Chain Resource Cooperative at North Carolina State University. 127 p.
IMPLAN LLC. 2015. 2014 North Carolina database. Huntersville, NC.
Jeuck, J, Bardon, R (2015) 2014 income of North Carolina timber harvested and delivered to mills. https://forestry.ces.ncsu.edu/county-income-and-economic-data/.
Matthews, HS, Hendrickson, CT, Matthews, DH (2015) Life cycle assessment: Quantitative approaches for decisions that matter. lcatextbook.com.
McConnell, TE, Jeuck, J, Bardon, R, Hazel, D (2016) North Carolina's forests and forest products industry by the numbers, 2013. North Carolina Cooperative Extension Service, Raleigh, NC. 10 p.
SAS Institute. 2013. Version 9.4. SAS Institute, Cary, NC.
Schaffer, WA (1999) Regional impact models. Regional Research Institute, West Virginia University, Morgantown, West Virginia. 81 p.
Seung, CK (2015) Untangling economic impacts for Alaska fisheries: A structural path analysis. Mar Res Econ 30(3):331-347.
USDC Census Bureau (2016) North American Industry Classification System (NAICS). http://www.census.gov/eos/www/naics/. Last accessed April 24, 2016.