Temporal Dynamics of Production Technology and Final Demand: Evaluating New York's Forest Sector Output Contribution along its Supply Chain and Value Chain.

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Abstract

This study examines the trend of economic contribution of the NYS Forest Sector over a 22-year period, focusing on how the sector has influenced the state's economy through its supply and value chains. Utilizing the Input-Output framework, the analysis looks into the sector's role in supporting local industries by providing inputs and purchasing outputs and how shifts in production technology and final demand have impacted its economic contributions over time. The total output change was decomposed over time to analyze the changes in the sector's economic contribution attributed to the changes in Production Technology and the changes in Final Demand. Further, the column space expansion of these changes was carried out by diagonalizing the final demand vector, allowing us to examine the detailed study of trend analysis along the supply and value chains of the sector. The developed model was used to study the dynamics of production technology and the final demand of New York State's Forest Sector.

The study reveals a significant decline in the New York Forest Sector's output, attributable to reduced demand and external economic pressures, including the impacts of the 2008-2009 Great Recession and the COVID-19 pandemic. Despite an increase in local input usage, which contributed to a 4.2% rise in output due to technological advancements, the overwhelming decrease in final demand led to a substantial fall in overall sector output. In fact, over the 22 years, the sector experienced a notable downturn, with a 33.3% decrease in production along its supply chain. The study further identifies a declining demand for forest products within the sector's value chain. Over 22 years, the NY Forest Sector's total gross output decreased by about 34%, of which 30% was attributed to the change in final demand and 4% was attributed to technological change. However, a modest recovery observed in 2022 indicates a potential shift towards more localized supply chains, suggesting a growing preference for intra-state trade, which could provide long-term benefits to the sector. Further, despite the reduction in total output contribution, the NY Forest Sector exhibited signs of resilience and potential for recovery, particularly in the years following the great recession and up until the onset of the pandemic. The findings highlight the importance of understanding sector-specific dynamics and the need for targeted policy interventions to support the forest sector's resilience and growth.

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1. Introduction

Economic contribution analysis measures the importance or the role of any sectors/industries within the economic region (Henderson et al., 2017; Parajuli et al., 2018; Watson et al., 2015). Importance or the role played by any industry within the region can be measured by quantifying how the industry is supporting other local industries either by purchasing their output or by providing them the raw materials or inputs that those industries require for their production (Cavo et al., 2023a, 2023b; Watson et al., 2015). Economic contribution analysis uses the Input-Output (I-O) or a Social Accounting Matrices (SAM) framework, whose fundamental purpose is to analyze the interdependence of industries in an economy. Different stakeholders often use these assessments to highlight and inform the industry's economic significance to those in policymaking and legislative positions (Henderson et al., 2017; Joshi et al., 2017; Watson et al., 2007). As emphasized by Tanjuakio et al. (1996), contribution analysis provides local officials with an essential perspective as they formulate policies and decide budget priorities for the continuous economic development of the region.

Contribution analysis has been used widely in the field of Forestry and the Natural Resource sectors (Cavo et al., 2023a, 2023b; Dahal et al., 2020; Henderson et al., 2017; Joshi et al., 2017; Parajuli et al., 2018). Typically, state forestry agencies and academic institutions perform these analyses at state and county levels, illustrating the importance of forestry and related natural-resource industries to the economy (Parajuli et al., 2018). In general, the contribution analysis is conducted on an annual basis and reports the contribution of a Sector in a given year in a given region. However, trend analyses, such as the one performed by Cavo et al. (2023a), for the NYS Forest sector add a new dimension to the contribution analysis, which can be helpful for different stakeholders, such as business analysts, business owners, economists, or policymakers to figure out how the industry dynamics are changing over time. The authors discovered that the NYS Forest Sector's contribution towards the state economy in terms of output production, employment generation, labor income, and Gross Domestic Product (GDP) is declining over the study time horizon. With the start of the 21st century, New York State's (NYS) economy faced a few ups and downs, primarily due to the great recession of 2008-2009 and the global COVID-19 pandemic. These economic downturns impacted several individual sectors, and the NYS Forest Sector was not the exception (Cavo et al., 2023a, 2023b).

While trend analysis reveals the sectoral changes in economic contribution over time, it often lacks insight into the drivers behind these changes. This gap highlights the need for an approach that not only provides the trend but also investigates the causes of change, whether they stem from shifts in production technology (describes the production function of the industries) or changes in exogenous final demand components such as exports and household consumption. One of the straightforward solutions is employing a decomposition approach described by Miller & Blair (2009, p. 595) and Skolka (1984, 1989). However, this approach decomposed the total change in output due to the change in production technology and the change in final demand. It only provides the vector of change in gross output or the change in the output along the industry value chain. It does not provide insights into the change in contribution along the supply chain. To overcome this gap, we combined the decomposition approach with the Gross-Base analysis methodology as introduced by Waters et al. (1999) and illustrated by Watson et al. (2015). Although the model described by Watson et al. (2015) considered only the export as the exogenous component and generally known as the export base, I-O accounts allow the flexibility to consider other final demand components, such as households or government, for example, as an exogenous component (Cavo et al., 2023b). The advantage of doing so is that it simultaneously measures the contribution of all the existing sectors in two folds: contribution along the supply chain and contribution along the value chain. This new approach adds yet another dimension to contribution analysis, allowing a more detailed understanding of sectoral dynamics and their drivers. We use this approach to study the changes in output contribution of the NYS Forest Sector along its supply chain and value chain and the drivers of those changes. We employed data from a software company called Impact Analysis for Planning (IMPLAN). To simplify the analysis, all the forest-related industries, such as Forestry and Logging, Pulp and Paper Industries, solid wood Product industries, and wood furniture Industries, are aggregated into a single sector, and the rest of the industries are aggregated based on the 2-digit North American Industrial Classification (NAIC) Schema.

2. Method

Linear transformation of the I-O accounts gives the total output vector(x)) as a function of Leontief inverse (L) and the exogenous final demand component (f) as in equation [1].

$$x = Lf \qquad [1]$$

For the purpose of this study, let's define x^t, L^t, and f^t as a total output vector, Leontief inverse and the exogenous final demand at time $'t'$. This allows us to modify equation [1] to study the change in total output vector over a given period as in equation [2], where $\Delta x = x^t - x^0$ is a change in total output vector from the base year to the year $'t'$, L^t, and f^t are as defined earlier, and L^0, and f^0 represents the Leontief inverse and exogenous final demand at the beginning or the base year.

$$\Delta x = L^t f^t - L^0 f^0 \qquad [2]$$

With some mathematical algebra, equation [2] can be modified as in equation [3], where a change in the production technology ($\Delta L = L^t - L^0$) is weighted by the final demand at base year, and the change in final demand ($\Delta f = f^t - f^0$) is weighted by the Production Technology of year $'t'$. Here, the 1st term, $(\Delta L)f^0$ gives the change in gross output due to a change in production technology, and the second term, $L^t(\Delta f)$ gives the change in gross output due to a change in final demand.

$$\Delta x = (\Delta L)f^0 + L^t(\Delta f) \qquad [3]$$

Equation [3] gives the two vectors of $(n \times 1)$, where $'n'$ is the number of industries, that decomposed the change in total gross output by two drivers. Column space expansion of these vectors converts the $(n \times 1)$ vectors into the matrix of $(n \times n)$, allowing us to study these changes in more detail.

Column space expansion of the total output vector can be simply performed by diagonalizing the final demand vector into the matrix of $(n \times n)$, which converts the equation [1] into equation [4]. Here the $'O'$ is the total output matrix, where the row represents the output produced by industry $'i'$ to satisfy the final demand of all the industries along its value chain. On the other hand, the column represents the total output produced by all the industries along the supply chain of industry $'j'$ to satisfy its final demand. In equation [4], $\hat{f}$ is the diagonalized final demand of dimension $(n \times n)$, where the principle diagonal elements contain the final demand of sector 'j', whereas all off-diagonal elements are zero.

$$O = L\hat{f} \qquad [4]$$

Using a similar methodology, equation [3] can be converted as in equation [5], where $\Delta O = O^t - O^0$ and $\widehat{\Delta f} = \widehat{f^t} - \widehat{f^0}$.

$$\underbrace{\Delta O}_{\substack{Total\ change}} = \underbrace{(\Delta L)\widehat{f^0}}_{\substack{Change\ drived \\ by \\ Production\ Technology}} + \underbrace{L^t(\widehat{\Delta f})}_{\substack{Change\ drived \\ by \\ Final\ Demand}} \qquad [5]$$

Looking across the column of matrix ΔO or Δo_{ij}, where $i \in (1, \dots, n)$ and $'j'$ remains constant, represents the total change in the output contribution along the supply chain of sector $'j'$ between given time periods. To be more specific, it gives the total change in the purchasing behavior of sector $'j'$ with sector $'i'$. Similarly, looking across the row of matrix ΔO or Δo_{ij}, where $j \in (1, \dots, n)$ and $'i'$ remains constant, represents the total change in the output contribution along the value chain of sector $'i'$ between given time periods. In other words, it represents the total change in the distribution of output by sector $'i'$ to sector $'j'$.

Each row and column of the two terms in equation [5], namely $(\Delta L)\widehat{f^t}$ and $L^0(\widehat{\Delta f})$ can also be interpreted in the same way. The 1st term gives the change in output contribution along the supply chain and value chain of any industry due to the change in the production technology or the change in inter-industry linkages over time. On the other hand, the second term measures the change in output contribution along the supply chain and value chain of a specific sector due to the change in its output from the final demand component.

Although the equation [5] can be used to evaluate the very specific concerns like "changes in transaction between any given sectors for a given time period" this study only presents the aggregated results or the column and row sums of each of the three components [Equation 6-9] of the equation [5]. However, detailed analysis is available upon request.

Change in total output generated along the supply chain of industry $'j'$ due to a change in production technology from the base year to year $'t'$:

$$\Delta p_j^{supply\ chain} = \sum_{i=1}^{n} \Delta l_{ij} f_j^0 \qquad [6]$$

Change in total output produced by industry $'i'$ or the output generated along the value chain of industry $'i'$ due to a change in production technology from the base year to year $'t'$:

$$\Delta p_i^{value\ chain} = \sum_{j=1}^{n} \Delta l_{ij} f_j^0 \qquad [7]$$

Change in total output generated along the supply chain of industry $'j'$ due to a change in due to a change in its final demand from base year to year $'t'$:

$$\Delta q_j^{supply\ chain} = \sum_{i=1}^{n} l_{ij}^t \Delta f_j \qquad [8]$$

Change in total output produced by industry $'i'$ or the output generated along the value chain of industry $'i'$ due to a change in final demand of all the industries in its value chain:

$$\Delta q_i^{value\ chain} = \sum_{j=1}^{n} l_{ij}^t \Delta f_j \qquad [9]$$

The model in equation [5] can be modified to study the change in contribution in terms of employment, value-added, labor income, and other indicators of interest, given the temporal dynamics of production technology and final demand. It can be accomplished simply by pre-multiplying the equation [5] by the coefficient of indicator of interest. This study, however, only focused on the output contribution.

3. Results and Discussion

During the period of 22 years, the NYS Forest Sector has faced several economic ups and downs, and it was also reflected in the output generation along its supply chain and its value chain. Section 3.1 presents and discusses the changes in the output of the NYS Forest Sector along its supply chain, and section 3.2 discusses the output changes along its value chain. All the amounts are real in the 2023 United States Dollar (USD).

3.1 Supply Chain Output Contribution

At the beginning of the 21st century or in 2001, the NYS Forest Sector generated about $21.9 billion in output along its supply chain. By 2022, however, this figure had declined by about 33.3% to $14.6 billion, reflecting the sector's vulnerability to external economic pressures and shifts in demand. As presented in Table 1 and Figure 1, the drop was more pronounced in the first decade, or from 2001 to 2011, than from 2011 to 2022. During the years 2001-2011, the Forest Sector's total output along its supply chain decreased by around 29.3%. This downturn can be largely attributed to the impact of the Great Recession of 2008-2009, which led to a significant contraction in economic activity worldwide. The recession affected consumer spending (Verick & Islam, 2010), investment (Imbs, 2010; Verick & Islam, 2010), and credit availability (Verick & Islam, 2010), which might be a reason leading to reduced demand for forest products and a consequent decrease in the sector's output.

The NYS Forest Sector began to recover in 2012 and increased its supply chain output from $15.5 billion in 2011 to $19.4 billion in 2016. However, it started to decline slowly after 2016 until 2020. Subsequently, the sector experienced a gradual decline in output from 2016 through to 2020. Despite this slight downturn, the sectors show economic resilience and the potential for growth within this decade. However, the COVID-19 pandemic worsened things, causing the sector's supply chain output to drop from $17.1 billion in 2020 to $14.9 billion in 2021 and even further to $14.6 billion in 2022.

Table 1: Contribution of NYS Forest Sector in terms of output production along their supply chain and the decomposition of the change in contribution. All amounts are in millions of USD.

Year	*Total Output along the Supply chain*	*Change due to*		*Total Change Equation [6]+[8]*
		Production Technology Equation [6]	*Final Demand Equation [8]*	
2001	$21,870.42	-	-	-
2002	$22,062.31	($60.33)	$252	$252.22
2003	$20,638.84	($23.98)	($1,208)	($1,207.60)
2004	$20,045.87	$94.70	($1,919)	($1,919.24)
2005	$20,216.22	$217.54	($1,872)	($1,871.73)
2006	$19,947.59	$77.49	($2,000)	($2,000.32)
2007	$19,840.09	$126.29	($2,157)	($2,156.61)
2008	$18,013.08	$173.87	($4,031)	($4,031.20)
2009	$16,383.38	($342.43)	($5,145)	($5,144.60)
2010	$16,378.88	$388.09	($5,880)	($5,879.63)
2011	$15,466.46	$507.30	($6,911)	($6,911.25)
2012	$16,400.46	$687.12	($6,157)	($6,157.08)
2013	$16,977.90	$532.24	($5,425)	($5,424.75)
2014	$17,258.40	$450.12	($5,062)	($5,062.13)
2015	$19,373.72	$651.40	($3,148)	($3,148.09)
2016	$19,447.09	$629.51	($3,053)	($3,052.83)
2017	$18,685.45	$788.84	($3,974)	($3,973.81)
2018	$17,328.55	$469.19	($5,011)	($5,011.05)
2019	$17,462.78	$490.16	($4,898)	($4,897.80)
2020	$17,080.19	$460.61	($5,251)	($5,250.83)
2021	$14,921.59	$418.59	($7,367)	($7,367.41)
2022	$14,584.92	$919.13	($8,205)	($8,204.62)

As presented in Table 1 and Figure 1, this decrease in output along the supply chain of the NYS Forest Sector was attributed to the decrease in demand of the NYS Forest output from the exogenous Final demand components. Except in 2002, the exogenous final demand for NYS Forest Sector Output never exceeded nor even reached the level of 2001. On the other hand, output production due to technological change increased from 2001 to 2022. There was a slight drop in 2002, 2003, and 2009 during the global recession. Except for that, the NYS Forest Sector's change in output due to changes in production technology was always positive and gradually increasing compared to 2001. Between 2001 and 2022, output attributable to technological change increased by approximately $919 million, or 4.2%. This indicates a growing reliance on local input and a shift away from importing goods and services, contributing positively to the sector's output.

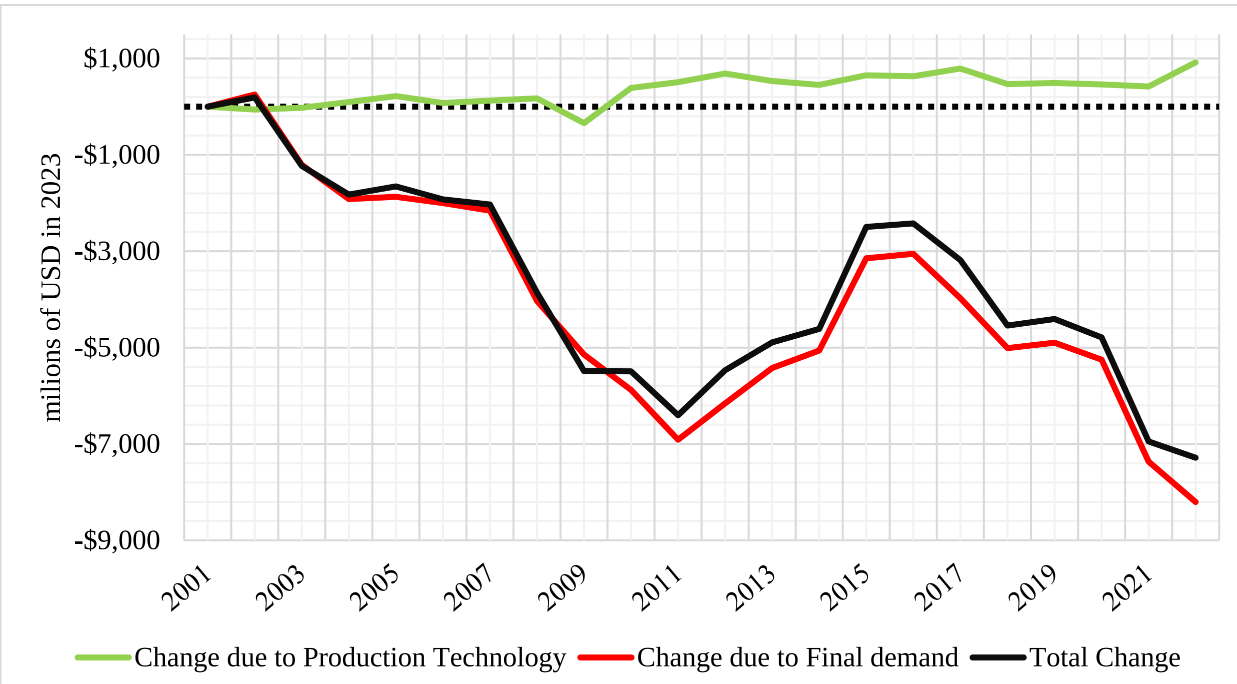

Figure 1: Change in output production along the supply chain of NYS Forest Sector between 2001 to 2022.

Although the NYS Forest Sector has increased its output along the supply chain due to increasing the use of local goods and services and tried to pull up the total output production, there is a decrease in the demand for NYS Forest Sector Output from the Exogenous Final Demand components is so severe that it pulled down the total contribution extensively. The output production along the supply chain of NYS Forest Sector decreased by around 31.6% in the 2011-post great recession of 2008-209. It showed some positive recovery after that, which was attributed to economic resilience; however, again, it started to drop after 2016 and faced a severe drop during the post-COVID period. Compared to 2001, the total output produced along the NYS Forest Sector supply chain decreased by $8.2 billion in 2022. It is evident that when there is a decrease in final demand for any sector, the rest of the sector in the supply chain is also required to decrease their production, which is attributable to satisfying the final demand of that sector. This results in consistently decreasing the total output production along the supply chain. This can be easily observed in Figure 1, where the line graph for total output is in the middle of the final demand and Production Technology. This decrease in demand, particularly from key components such as personal consumption, government spending, investment, and exports, underscores the challenges faced by the sector in maintaining its production levels.

3.2 Value Chain Output Contribution

The output produced along the value chain, or the value chain output contribution, simply represents the total gross output produced by the sector. The output along the value chain of the Forest Sector reflects the supporting role of the Forest Sector by distributing its output to satisfy the exogenous final demand of other sectors within the region. As presented in Table 2, in 2001, the NYS Forest Sector produced a total output worth $21.6 billion, which decreased gradually, and by 2022, it decreased by 34% to $14.3 billion. This decline follows a similar pattern as a supply chain side, where the total gross output reduced gradually up to 2007 and then sharply during the Great Recession—a global financial crisis that had a cascading effect on multiple sectors, including the Forest Sector. In 2011, the total gross output of the NYS Forest Sector was worth $14.5 billion, which was 32.9% less than the total gross output in 2001 (Table 2, Figure 2). Again, after 2011, the Forest Sector began to recover, characterizing its economic resilience, which lasted until 2016. The total gross output increased from $14.5 billion in 2011 to $18.6 billion in 2016. The gradual decrease and the COVID-19 exaggeration decreased the total gross output to $14.6 billion in 2021 and a further $14.3 billion in 2022.

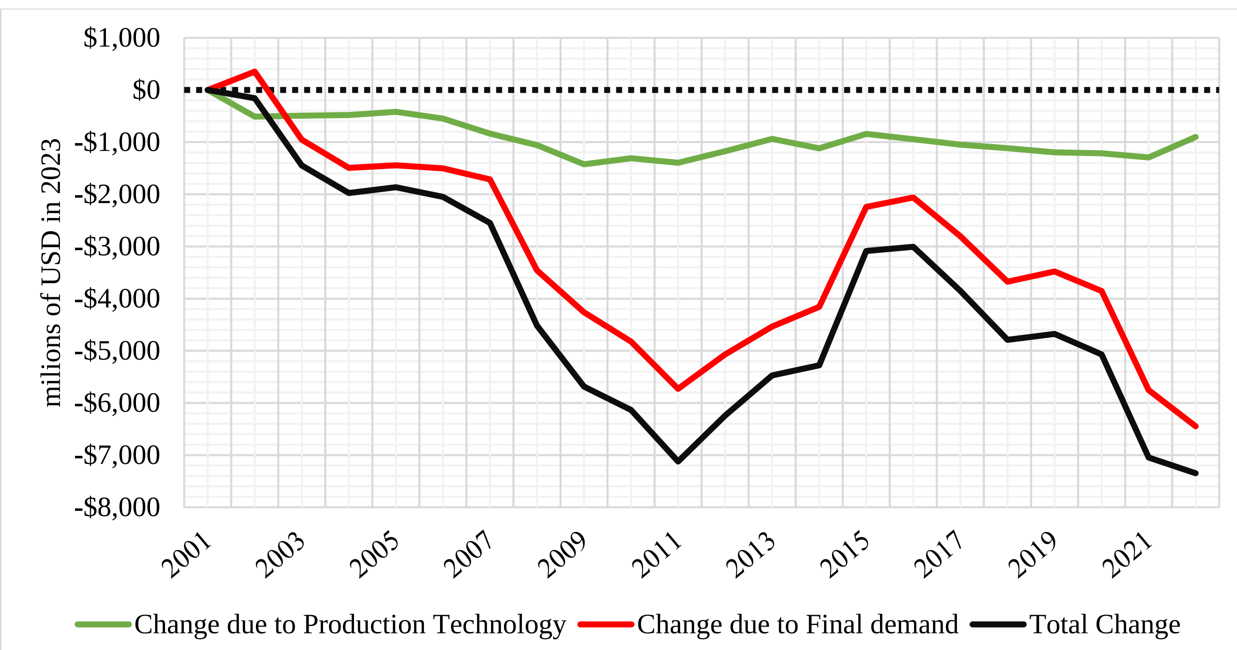

Figure 2: Change in output production along the value chain of NYS Forest Sector between 2001 to 2022.

Table 2: Contribution of NYS Forest Sector in terms of output production along their value chain and the decomposition of the change in contribution. All amounts are in millions of USD.

Year	*Total Output along the Value chain*	*Change due to*		*Total Change Equation [7]+[9]*
		Production Technology Equation [7]	*Final Demand Equation [9]*	
2001	$21,625.59			
2002	$21,467.42	($509.51)	$351.34	($158.17)
2003	$20,179.02	($493.63)	($952.94)	($1,446.57)
2004	$19,651.38	($480.88)	($1,493.33)	($1,974.21)
2005	$19,761.63	($418.54)	($1,445.41)	($1,863.95)
2006	$19,575.79	($546.85)	($1,502.95)	($2,049.80)
2007	$19,075.32	($834.87)	($1,715.40)	($2,550.27)
2008	$17,109.91	($1,057.34)	($3,458.34)	($4,515.68)
2009	$15,940.27	($1,424.22)	($4,261.10)	($5,685.31)
2010	$15,489.79	($1,310.32)	($4,825.47)	($6,135.80)
2011	$14,501.73	($1,394.84)	($5,729.03)	($7,123.86)
2012	$15,384.28	($1,172.62)	($5,068.69)	($6,241.31)
2013	$16,153.96	($936.54)	($4,535.09)	($5,471.63)
2014	$16,348.11	($1,120.25)	($4,157.23)	($5,277.48)
2015	$18,538.65	($843.39)	($2,243.55)	($3,086.93)
2016	$18,618.55	($944.82)	($2,062.22)	($3,007.04)
2017	$17,773.33	($1,047.31)	($2,804.95)	($3,852.25)
2018	$16,834.72	($1,114.63)	($3,676.24)	($4,790.87)
2019	$16,950.28	($1,196.41)	($3,478.89)	($4,675.30)
2020	$16,556.44	($1,213.87)	($3,855.27)	($5,069.14)
2021	$14,580.04	($1,292.77)	($5,752.78)	($7,045.55)
2022	$14,277.28	($901.23)	($6,447.08)	($7,348.31)

Unlike the Supply chain output contribution, both the change in production technology along the value chain of NYS Forest Sector and the change in the exogenous final demand of all the sectors along its value chain is responsible for the decrease in total gross production[4]. Among the two drivers, changes in the final demand of the sectors along the value chain of the NYS Forest Sector are primarily responsible for this decline in output. This indicates that the NYS Forest Sector is heavily dependent on the demand from other sectors within the region and that when this demand falters, the sector struggles to maintain its output levels. It follows a somewhat similar pattern as the total output change and the change in output along the supply chain side (Figure 2).

On the other hand, changes in the gross output due to changes in production technology are utterly different from that of the supply chain side. As observed in Table 2 and Figure 2, output production

[4] Here, one should note that since the I-O is a double-bookkeeping account, the self-consumption and the exogenous final demand of a sector of interest (NYS Forest Sector in this case) is included in both of its supply chain and the value chain (Watson et al., 2015).

of the NYS Forest Sector is consistently below the 2001 level from 2002 to 2022 due to the change in production technology along its value chain. It dropped severely in 2009, dropping by 6.6% compared to 2001. It showed a certain improvement between 2011 and 2015 but again declined after that. In 2021, it again reached a 6% drop compared to 2001. In recent years or in 2022, there was a small bump or a decrease in value chain output due to changes in production technology, changing from -$1.3 billion in 2021 to $901 million in 2022. Since the changes in the production technology along the supply chain of the Forest Sector represent the change in the purchasing behavior of other local sectors with the NYS Forest Sector, it might be a sign of further improvement of the purchasing behavior of other local sectors to purchase the local goods and services produced by the NYS forest Sector rather than importing them.

4. Summary

NYS Forest Sector experienced a significant decline in its output contribution along its supply chain and value chain, primarily due to decreased demand and external economic pressures, including the great recession of 2008-2009 and the COVID-19 pandemic. From 2001 to 2022, the sector's output along its supply chain dropped by 33.3%, and its value chain output decreased by 34%. In the supply chain of NYS Forest Sector, although it increases the proportion of use of the local goods and services as their inputs, which in fact was responsible for the increase in output by 4.2% between 2001 and 2022, severe declines in exogenous final demand led to a substantial reduction in total sector output. On the other hand, the study also uncovered a declining trend in the purchasing behavior of industries within the NYS Forest Sector's value chain, indicating a consistent decrease in the demand for forest products over time. However, the slight increase in 2022 may indicate an improving trend where local sectors are starting to purchase more goods and services from the NYS Forest Sector rather than importing them. This could point to a shift towards more localized supply chains and a greater emphasis on intra-state trade, which may benefit the sector in the long term.

One of the paper's shortcomings is that it examined the Forest Sector at a highly aggregated level, which might suffer from aggregation bias. On the positive side, this paper presents possibilities for further research in two specific directions: First, examining more disaggregated industry data can be crucial to identifying the primary forest industries responsible for the sector's overall output decline. This could shed light on specific areas within the sector that require targeted interventions or support at the policy level. Second, by disaggregating the final demand components, the study could look deeper into which specific components are responsible for the decline in total output production. Such an analysis would offer valuable insights into the sector's demand shifts, enabling stakeholders to develop more specific and effective strategies for addressing these challenges and maintaining sectoral resilience.

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