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Past, Present and Future of Maine's Pulp and Paper Industry

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PAST, PRESENT AND FUTURE OF MAINE'S PULP AND PAPER INDUSTRY

By

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By Ariel Alejandro Listo Argul

Thesis Co-Advisors: Dr. Adam J. Daigneault and Dr. Jonathan Rubin

An Abstract of the Thesis Presented
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The pulp and paper industry has historically been of paramount importance for the state of Maine, both from cultural and economic perspectives. The industry has been a vital part of the forest products economy and a large contributor to employment and state gross domestic product (GDP). However, the number of pulp and paper mills in Maine has declined sharply in the last few decades, deeply harming employment levels, local economies and the forest products sector of the most heavily forested state in the nation. This phenomenon has sparked efforts to understand the factors behind the downfall of Maine's pulp and paper industry and investigate potential developments to reinvigorate the industry and its crucial significance to Maine. This work aims to contribute to these endeavors.

This thesis is divided in three chapters. First, Chapter 1 provides a historical background of the pulp and paper industry, discusses its current state and analyzes the validity of and trends in the factors which are commonly believed to have substantially affected this sector in Maine. Chapter 2 provides empirical evidence on the relationship between employment levels in the pulp and paper industry and the so-called "Cluster Rule," the first integrated, multi-media regulation released by the Environmental Protection Agency (EPA) in 1998. Lastly, Chapter 3 discusses the research conducted on the socio- and techno-economic feasibility of re-purposing idle pulp and paper facilities in the state of Maine into wood-based thermal deoxygenation (TDO) "drop-in" biofuel refineries.

As conclusions, change in paper and paperboard products demand, competition from foreign advanced and low-cost pulp and paper facilities, and price increments in key inputs for domestic pulp and paper mills are identified as some of the major factors explaining its recent downfall. Additionally, strong evidence is found that the Cluster Rule had net negative impacts on national employment levels from the pulp and paper industry ranging from 17% to 24% declines, and weaker evidence of a roughly 30% negative effect on Northeastern pulp and paper mills. Lastly, several studies concluded, from various perspectives and different scenarios, that TDO biofuel refineries developments in Maine are socioeconomically feasible.

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I am deeply grateful to my advisor, Dr. Adam Daigneault, for his support and advice throughout my career at the University of Maine. I will always appreciate his pragmatism and resourcefulness. I would also like to thank my committee members, Dr. Jonathan Rubin and Dr. Gary Hunt, for their guidance, words of encouragement and support.

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CHAPTER 1
THE STATE OF THE PULP AND PAPER INDUSTRY IN MAINE

1.1 Introduction

Maine's comparative advantage in the paper-making industry was realized when rags became scarce and expensive and mills switched to wood as their fiber source to manufacture paper. Abundant forests and numerous rivers for transportation purposes attracted investors and sparked a tremendous expansion in the pulp and paper industry during the late 19th century and early 20th century. Mills were built alongside rivers and entire towns were built around mills. By 1890, there were 25 pulp mills in Maine, including the largest one in the world, and during the first half of the 20th century, Maine became the nation's leading paper-producing state. The industry became a vital part of the forest products economy and a large contributor to employment and gross state product (Smith, 1970).

Today, the panorama of this once-vibrant industry is different. Over 20 facilities have closed down in the past few decades and employment levels have plummeted. Competition from foreign mills is fierce and population in Maine's paper towns has decreased sharply. These declines were exacerbated during the 2007-2009 recession years (Woodall et al., 2011). Simultaneously, paper consumption in the United States in the last decade has been declining (Howard and Jones, 2016), a change that many attribute to the shift of advertising and communication technology to electronic media. Others argue that pressures from other sources, such as environmental movements have also played a role in shaping the industry's status quo (Sonnenfeld, 2002; Bouvier, 2010).

That the paper industry has undergone substantial structural changes in the last few decades in Maine and in the entire United States, regardless of the discrepancies over their causes, is indisputable. This chapter will provide a historical overview of the pulp and paper industry in Maine and explore some of the reasons most cited as the explanatory factors for its current state.

1.2 Background

1.2.1 History of Maine's Pulp and Paper Industry

1.2.1.1 Colonial Times Until 1969

Paper-making in Maine dates back to the 1730s, when the first mill in what at the time was part of the Province of Massachusetts Bay was founded on the Presumscott River between Westbrook and Falmouth[1]. During this period, paper was hand-made out of rags, and since few people in the colonies read and only the first rudimentary newspapers were being printed, mills only served their low, local demand. In 1854, Samuel Dennis Warren purchased the Westbrook mill and started the S.D. Warren Company. Two years later, this mill was the largest importer of rags in the world. At the time, most paper mills were located in Massachusetts, New York and Pennsylvania, and gradually grew in numbers as demand for paper increased along with interest in the civil war, newsprint, literacy and a growing population. These changes caused a shift from hand-manufacturing to machine production and a subsequent shortage of rags given the increasing pressure from mills to obtain their main raw material.

By 1860, an extensive search for new fibers capable of substituting the scarce and expensive rags led to the discovery of wood pulp for paper purposes. The Northeast, and especially Maine, one of the most heavily forested states in the country, had a vast supply of wood which attracted investors to the region. In addition to large forests, Maine had numerous rivers, which were the second blessing

[1] Most of the information for this section was obtained from "History of Papermaking in the United States (1691-1969)," by David Smith from The University of Maine

needed for pulp and paper mills. Rivers were mainly used as waterways for log-drives, which refer to the transportation of logs to mills through water bodies. Other benefits of rivers included energy generation and their use as waste outlets. By the end of the 19th century, mills had been expanding to various parts of the country, but the geographic distribution of the industry was clearly skewed towards forestlands. Its abundant natural resources gave Maine a comparative advantage in the pulp and paper industry, which was reflected in the number and dimension of pulp and paper mills in the state.

Maine never led the industry by number of facilities, but it hosted some of the largest and most productive mills. In 1877, Maine had 35 paper mills and ranked 6th in the country, well behind New York's 204 paper mills. However, the Westbrook mill became the largest paper mill in the world in 1880. The first pulp mill opened in Topsham in 1868, and by 1890, Maine already had 25 pulp mills. At the turn of the century, Maine was the largest pulp-producing state in the nation and the industry kept expanding. In 1900, Great Northern Paper opened a mill in Millinocket, which became the largest mill in the world at the time, and had expanded to East Millinocket and Madison by 1907. Mills followed in Rumford, Baileyville, Madawaska, and Bucksport shortly after. At the national level, there were 668 firms operating 754 paper mills and 245 pulp mills in 1914. By 1920, 700 firms owned a total of 804 pulp and paper mills, and by 1933 only 578 firms operated 777 paper mills and 261 pulp mills, suggesting a trend towards consolidation of firms.

Table 1.1. Distribution of Firms by Leading Paper-Making States

1914		1920		1933	
State/Region	Number of Firms	State/Region	Number of Firms	State/Region	Number of Firms
New York	153	New York	155	New York	109
Massachusetts	65	Massachusetts	65	Massachusetts	64
Pennsylvania	57	Pennsylvania	63	Pennsylvania	51
Wisconsin	48	Wisconsin	55	Ohio	46
Connecticut	47	Ohio	50	Wisconsin	39
Ohio	43	Connecticut	40	New Jersey	37
Michigan	42	Michigan	40	Michigan	35
New Jersey	27	New Jersey	39	Connecticut	28
N. Hampshire	27	N. Hampshire	25	Illinois	25
Maine	25	Indiana	23	**Maine**	24
Indiana	22	Illinois	22	N. Hampshire	21
Illinois	20	**Maine**	21	Washington	21
South	44	South	50	South	66
Pacific Coast	12	Pacific Coast	16	Pacific Coast	40
United States	668	United States	700	United States	578

Source: Smith, 1970

The remarkable expansionary trend of the industry in the state, and nationally, during most of the 20th century has been relatively immune to financial crises, the Great Depression and both World Wars. Firms like Maine's Great Northern Paper Company continually invested in their plants, increasing capacity and output, and consistently generating profits. Prospects for the industry were bright and, as such, higher learning institutions and laboratories opened programs and entire departments dedicated to the study of and training in the pulp and paper industry. The University of Maine pioneered such studies, opening a school of papermaking as early as 1913, only a decade after the School of Forest Resources had been founded.

While growth in number of mills had slowed down by the second quarter of the century, productivity in Maine's mills, fueled by large investments and discoveries of new technologies, continued its increasing trend. When Maine mills switched to kraft pulping processes, the state climbed to the very top of paper-producing states in the country, even while the entire industry had already reached the West Coast and the Southern states. By 1960, Maine was also a leader in coated paper, used for magazines and specialty paper, but competition from other regions of the country became more intense. The Southern mills, surrounded by Southern pine plantations, benefited largely from cardboard demand, which augmented the region's importance for the industry. Simultaneously, large investments helped Wisconsin steal Maine's title as the largest paper-producing state, and growth in the West Coast continued bringing new developments.

1.2.1.2 1970 to Present-Day

Maine's last mill was built in Skowhegan in 1981, owned by today's Sappi Fine Paper North America, breaking the state's capacity records and focused on the production of higher quality products. With the addition of the Skowhegan mill, Maine reached its peak capacity and output, but some smaller, old and outdated facilities failed to keep up with their in-state competitors and many went out of business (Maine Pulp Paper Association, n.d.). The concurrent advent of globalization also forced Maine's competitiveness to be contested against mills from virtually the entire world.

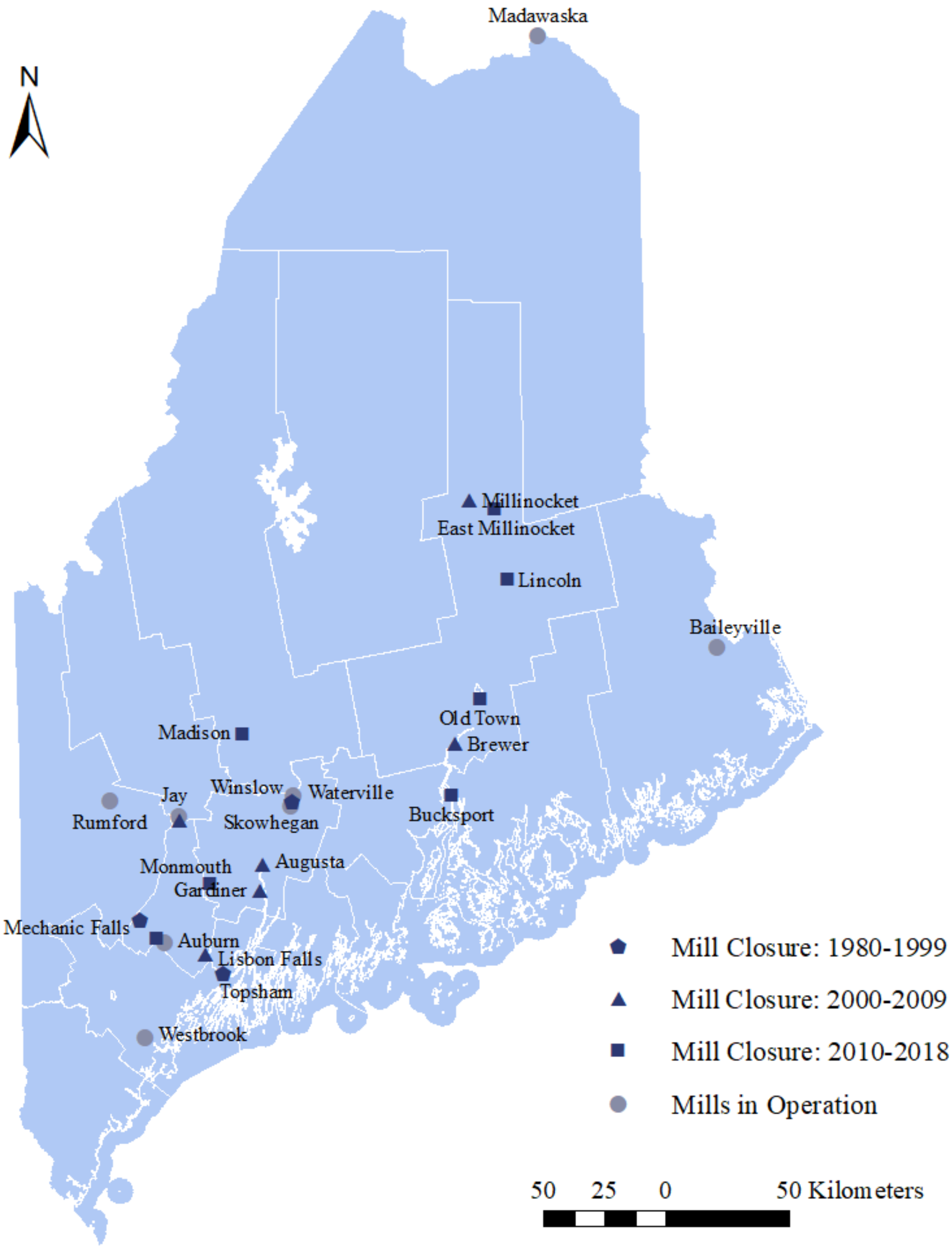
The outlook for this industry in the United States started to change during the last quarter of the last century. Nationally, employment levels ceased to increase and entered a long period of modest change which preceded a plunge that brought employment at pulp and paper mills back to 1940s' levels (Bureau of Labor Statistics, 2018). While this change in employment could have been driven, in part, by investments in technology that increase productivity, and aggravated by the recent financial crises, the number of plants across the country has also decreased. In particular, Maine was home to over 20 paper and pulp mills in 1980. Today, only 8 facilities remain operational and most of the shutdowns have occurred during the last decade. Table 1.2 lists the few facilities that remain in operation in the state. Figure 1.1 shows the geographic distribution of all mills that were operative in 1980 and their label indicates their current operational status.

Table 1.2. Pulp and Paper Mills Operating in Maine as of 2018

Town	Name	Type	Pulp Capacity	Paper Capacity
Auburn	Cascades Auburn Fiber, Inc.	Pulp mill	84,411st/y	N/A
Baileyville	Woodland Pulp, LLC	Pulp mill	450,287st/y	N/A
Jay	Verso Paper Corp.	Pulp and Paper	494,960st/y	633,178st/y
Madawaska	Twin Rivers Paper, LLC	Pulp and Paper	282,756st/y	367,629st/y
Skowhegan	Sappi Fine Paper North America	Pulp and Paper	561,082st/y	876,242st/y
Rumford	NewPage Corp.	Pulp and Paper	471,265st/y	522,890st/y
Waterville	Huhtamaki N.A.	Containers	N/A	N/A
Westbrook	Sappi Fine Paper North America	Pulp and Paper	4,050st/y	38,548st/y

P&P Capacity Data: 2015-2016 Lockwood-Post Directory of Pulp and Paper Mills

Figure 1.1. Distribution of Maine Mills by Operational Status - 1980-2018



Source: Maine Office of GIS and
Lockwood-Post Directory of Pulp and Paper Mills, Various editions

1.2.2 Economic Contribution

The role of the pulp and paper industry in the state of Maine has historically been of paramount economic and cultural importance. Hillard (2004) discussed the paternalistic role that the giant S. D. Warren firm, which owned the Westbrook mill (Sappi Fine Paper Westbrook today), played in its town. Like S. D. Warren, many mills helped build and grow their surrounding towns and communities. Mills would often supply essential services such as housing, libraries, schools, hospitals, etc. (Bouvier, 2009). A popular nickname for the town of East Millinocket, ME, noted in its official logo, is “The Town That Paper Made", recognizing the great deal of influence that the Great Northern’s mill had on the town’s existence.

Mills also contributed to economically sustainable population levels and the closure of mills in historically "paper towns" has been followed by an exodus of working-age population towards bigger urban centers within and outside of Maine. Figure 1.2 shows changes in labor force trends from 1990 to 2018 in towns that have experienced mill closures in the last few decades. This exodus has been most pronounced in regions such as the Millinocket area, a region highly dependent on its now idle paper mills.

Figure 1.2. Latest Labor Force Trends in Former Mill Towns

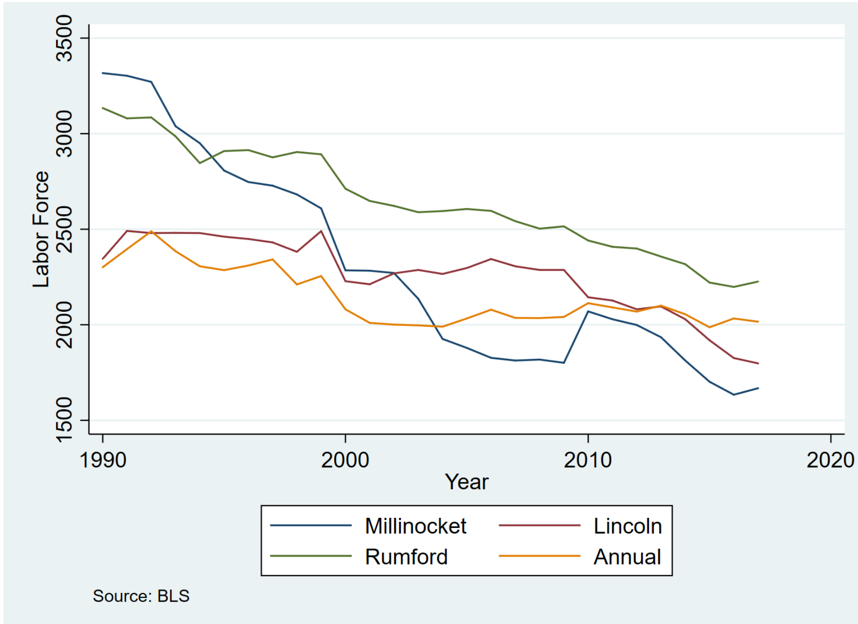
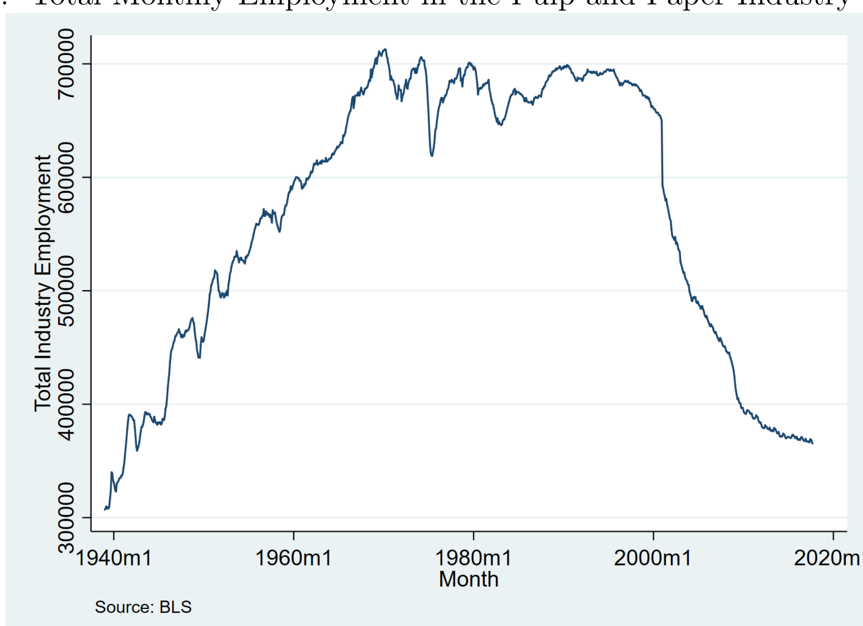


Figure 1.3 shows monthly data from the Bureau of Labor Statistics (BLS) Quarterly Census of Employment and Wages (QCEW) on total employment in the pulp and paper industry (NAICS 3221) in the U.S. from January 1939 to September 2017.

Figure 1.3. Total Monthly Employment in the Pulp and Paper Industry in the U.S.



The downward trend evident since the late 1990s and early 2000s is also prevalent in the Northeast region of the country and particularly pronounced in states such as Maine. Specifically, from 2001 to 2016, employment in the pulp and paper industry nationally has decreased from 561,536 to 369,484 jobs, representing a decline of 34.2%. Over the same period, Maine has seen a decrease in this industry from 10,208 to 3,399 jobs, which translates to a 66.7% loss in employment. Figure 1.4 shows total monthly employment in the pulp and paper industry in Maine since 1900. These data were obtained from Irland (2000) for pre-2001 values and from the Quarterly Census of Employment and Wages (QCEW) from BLS for the most recent values.

Figure 1.4. Total Monthly Employment in the Pulp and Paper Industry in Maine.

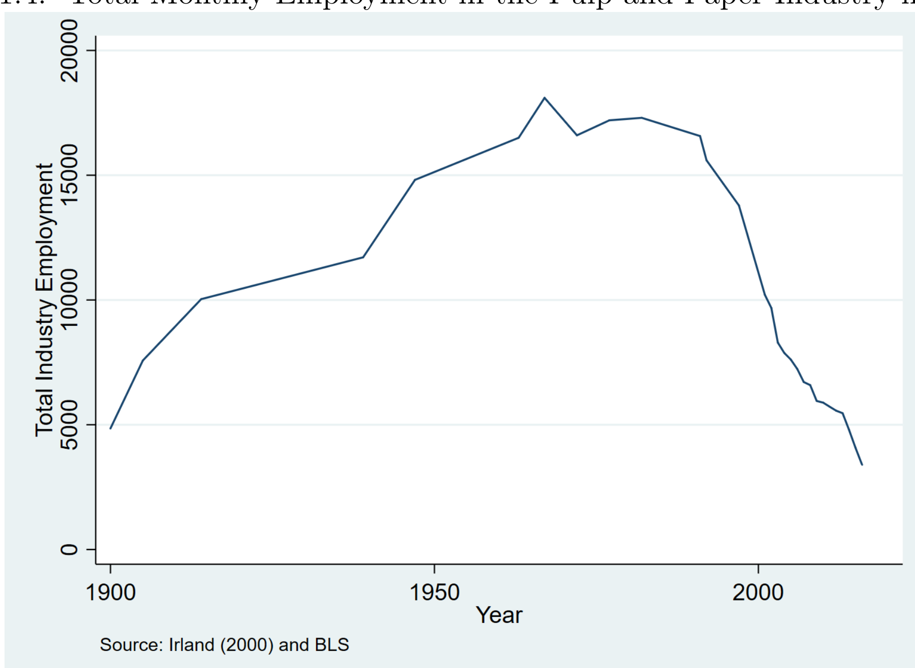


Table 1.3 focuses on the latest estimates on employment and wages from the pulp and paper industry (NAICS 3221) in Maine because it is since 2001 that the largest declines have occurred. Employment data are reported in absolute number of employees and wages are in thousands of dollars.

Table 1.3. Latest Employment and Wages Data from Maine's Pulp and Paper Industry

Year	Total Employment	Wages
2016	3399	277662
2015	4069	336759
2014	4790	361903
2013	5463	385023
2012	5564	386759
2011	5723	396177
2010	5886	397026
2009	5953	388807
2008	6588	441247
2007	6713	435828
2006	7236	467684
2005	7614	474792
2004	7876	483748
2003	8293	517785
2002	9680	549792
2001	10208	564674

Source: BLS

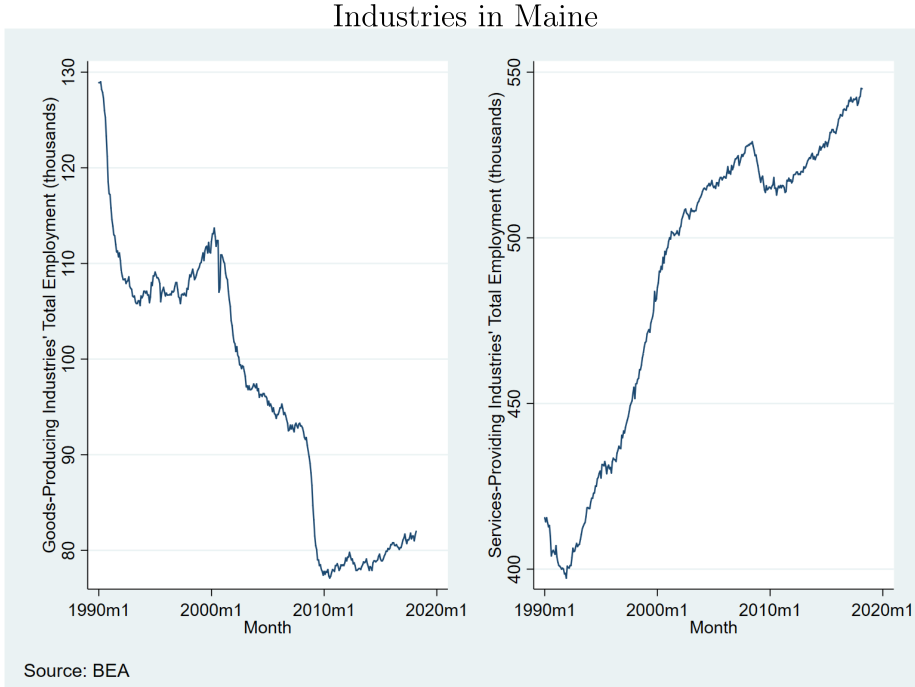
Although the contribution of the industry in terms of employment and wages to the state's economy has been declining, as evident from Table 1.3, the contribution of pulp and paper to the state's forest products industry remains strong. According to the American Forest & Paper Association (AF&PA), Maine's pulp and paper industry generated a third of employment, more than half of payroll income, and almost 80% in value of shipments of the total forest products industry in 2017 (AF&PA, 2017).

1.3 The Downfall of Pulp and Paper Mills

1.3.1 Overview

Changes in the pulp and paper industry in Maine have not occurred in isolation. In fact, the structure of employment in the state has evolved over the last few decades. The most apparent change is a shift from goods-producing employment towards the provision of services. Figure 1.5 displays total monthly employment in goods-producing and services-providing industries in Maine from 1990 to early 2018. While labor in manufacturing industries has declined by almost 40% in less than three decades, employment in service sectors over the same time-period has increased by a similar amount. Both downward and upward trends seem to have been exacerbated or dampened, respectively, by the 2007-2009 economic recession. However, the increasing tendency of jobs in service industries prevailed after the recession, paralleled by a modest grow in manufacturing labor.

Figure 1.5. Total Monthly Employment in Goods-Producing and Services-Providing Industries in Maine



Figures 1.6 and 1.7 show employment trends from the manufacturing and health and education industries, the two major sectors behind these trends in goods-producing and services-providing groups. Figures 1.8 and 1.9 exhibit these data in 12-month net employment change version between 1990 and early 2018. Health and education account for most of the gains in employment in the services industries. This is evident from these industries' remarkable consistency of positive

growth, shown in Figure 1.9. Although the industries' employment has increased at a decreasing rate during the last decade, mainly influenced by the last financial crisis, the latest data suggest that an increasing trend is gaining momentum. On the other hand, Figure 1.8 simply reinforces the negative outlook for the manufacturing sector which has only sporadically seen positive employment change, largely offset by sizable negative spikes.

Figure 1.6. Total Monthly Employment in Manufacturing Industries in Maine

Figure 1.7. Total Monthly Employment in Health and Education Industries in Maine

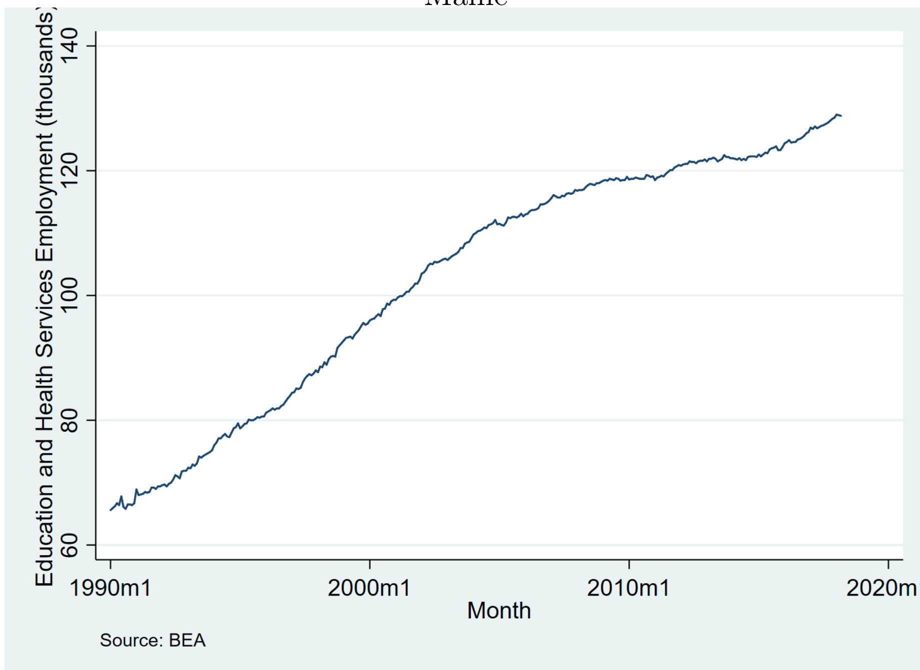
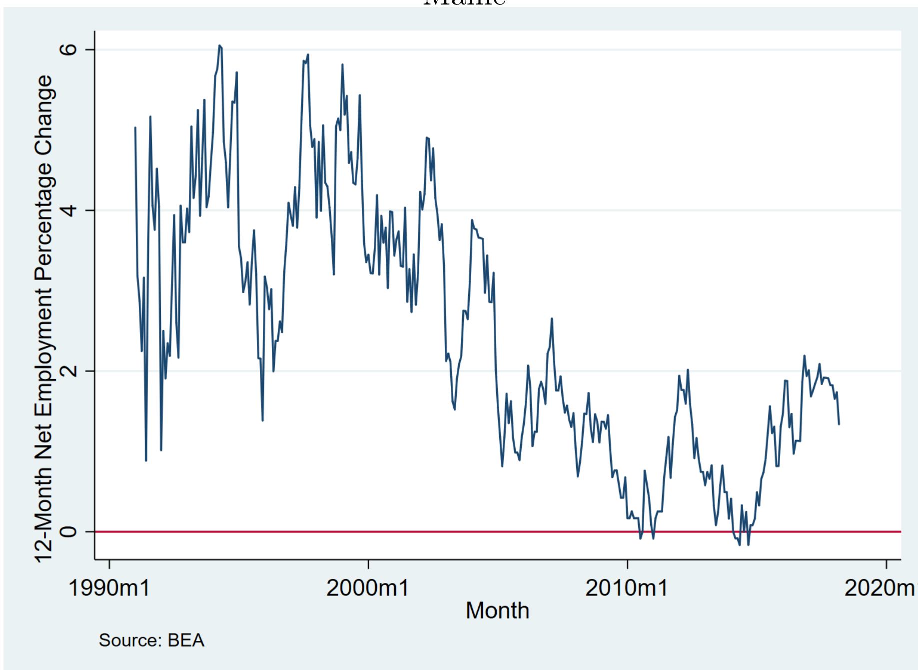


Figure 1.8. 12-Month Net Manufacturing Employment Change in Maine

Figure 1.9. 12-Month Net Education and Health Services Employment Change in Maine



Other sectors which have consistently sponsored job growth during the last few decades include the hospitality industry and the professional business services sector. The mining and logging industry, closely related to the pulp and paper sector, show relatively stationary employment changes revolving around 0, with a slight tendency towards negative growth. These employment change figures are included in the appendix.

In this hostile environment towards manufacturing jobs, the pulp and paper industry has seen the sharp declines in employment and number of operating facilities previously mentioned. Previous studies and research on this topic identify a combination of variables which helped create unfavorable economic conditions for the papermaking industry. These include subsidized and low-cost foreign competition, changes in demand, and input supply-side shocks. An exploration of these factors and their impact on the pulp and paper industry in Maine follows below.

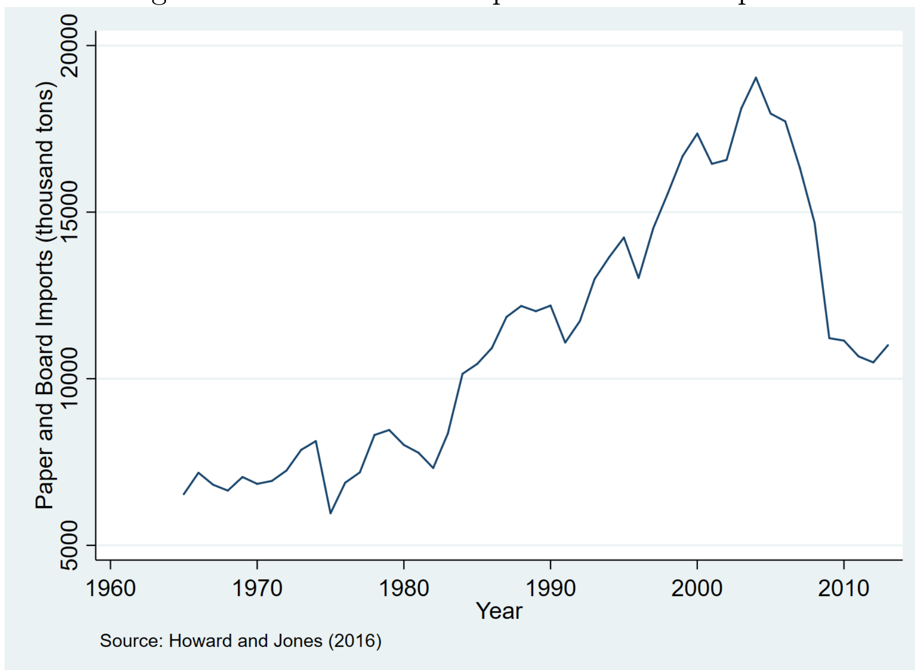
1.3.2 Drivers of Downfall

1.3.2.1 Foreign Competition

Maine's pulp and paper industry has constantly faced competition, but while regular paper was the most traded commodity and distances were barriers to trade, domestic paper mills did not pose a substantial threat. Only small and technologically outdated mills were the ones that occasionally failed to keep up with larger, sophisticated mills, often from within Maine. However, during the last quarter of the 20th century, while the nature of foreign trade became increasingly globalized, foreign competition from various parts of the world became a challenge to American mills. From Europe, new -or upgraded- large and advanced mills, mostly located in Scandinavia, started to compete with their American counterparts. Forest-abundant regions of Latin America, such as the northwestern portions of Brazil or industrial pulp plantations in Chile, fueled an expansion of the region's pulp and paper industry which resulted in exports to other regions, including the United States.

In the last decade, most new mills have been built in low-cost Asian countries such as China, Thailand, Indonesia and Vietnam (Hidayat and Yasuyuki, 2011; Herman, Yasuyuki, Phuong, 2012). Highly-productive and fast machinery, coupled with a low-cost labor, make Asian mills highly competitive in the global market and have significantly driven down prices for paper products on a global scale. For pollution-intensive industries such as the pulp and paper industry, some of these regions are also attractive due to their lax, or at least less restrictive, environmental regulations (Hidayat, 2007). In fact, U.S. paper and board imports have continuously increased as environmental regulations affecting the domestic pulp and paper industry, such as the so-called Cluster Rule, were introduced. Figure 1.10 shows total U.S. paper and board imports (excluding converted products) from 1965 to 2013, obtained from Howard and Jones (2016).

Figure 1.10. Total U.S. Paper and Board Imports



When it comes to wood pulp, the U.S. enjoys a moderate overall net trade surplus with China, Japan and Mexico as the largest consolidated export markets, and demand from the Sweden and Belgium as the fastest growing. Wood pulp imports originate predominantly from Canada and Brazil, with the Chilean market growing steadily (Chatham House Resource Trade Database, 2018).

The detrimental effect of foreign competition on the American industry is not simply realized through penetration in the domestic market and loss of local demand. By the end of the century, foreign competitors were also able to meet demand from markets that had historically relied on the U.S. for their supply of wood pulp and paper products. For example, the two largest exporters of wood pulp to the United States, Brazil and Canada, are also the first and second largest exporters of wood pulp to China, which is the U.S.'s primary export market (Chatham House Resource Trade Database, 2018; FAOSTAT, 2018). However, foreign competition is not the industry's demand only threat. The rapid emergence of electronic and digital technologies of communication have also recently played a role in reducing demand for paper.

1.3.2.2 Paper Demand: The Digital Era, Foreign Supply and Recycling

Figure 1.11. Total U.S. Paper and Board Consumption

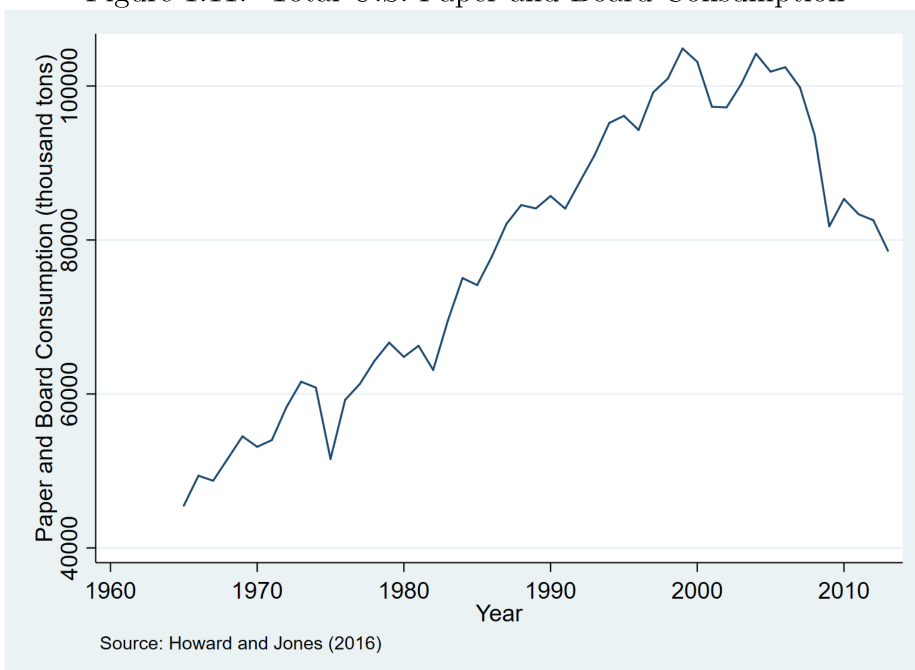


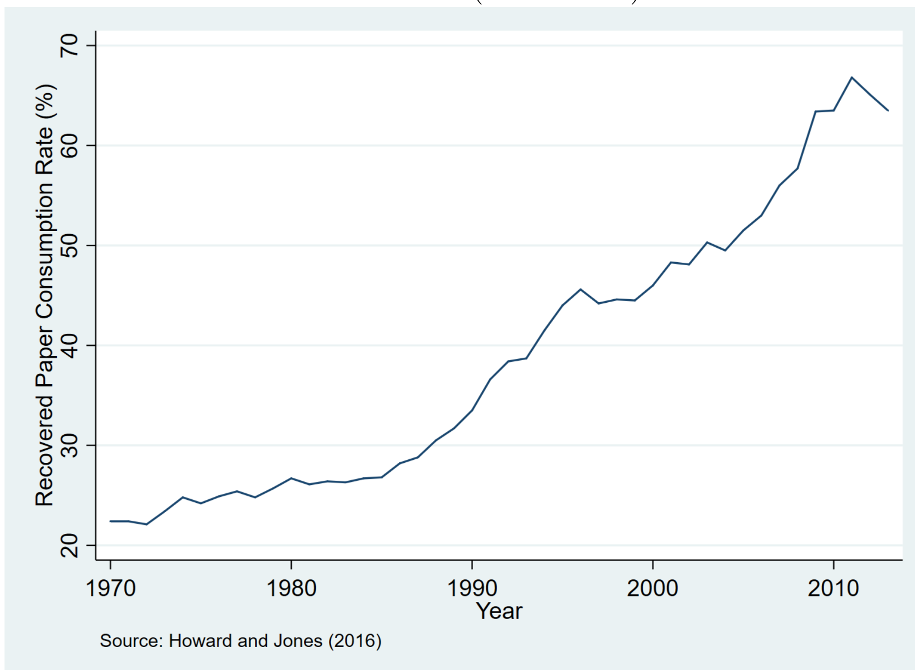
Figure 1.11 exhibits the behavior of paper and board (excluding wet machine board and construction grades) consumption in the United States over the last four decades. From 1965 until the late 1990s, the consumption of paper products has experienced exceptional growth. However, the latest data show a decrease which brings current U.S. consumption close to levels from the late 1980s. Many argue this rather recent depression in consumption is related to the rise of electronic media. Documents, articles, books, news and the like, are increasingly being distributed and consumed in digital form, often accessed via online sources. Some even argue that newsprint has become an inferior good, since its demand now declines with increases in income (Hurmekoski and Hetemaki, 2013). Yet, along with electronic

media is the impressive rise of online shopping in the past decades. Retailers that need to ship their products to consumers increase the demand for board products which make up most of the packaging material used in shipments in the United States. In 2018, the two largest packaging and container manufacturing markets were China, which accounted for close to 30%, and the United States, with approximately 15% of total global production (FAOSTAT, 2018). Nevertheless, the market for these products are not highly concentrated and most demand is met locally by medium-size facilities. In Maine, Waterville's Huhtamaki facility is mostly a packaging and container manufacturing plant.

The industry's outlook is also being shaped by remarkable achievements in recycling. For almost a decade, the recovery rate, which is the ratio of total recovered paper collected to new supply of paper and paperboard, has reached or surpassed 60%. In fact, the recovery rate peaked in 2016 at 67.2%. This means that during that year, 67.2% of the supply of paper had its origins in recovered paper. Additionally, according to the EPA[2], over 95% of the population of the United States has access to curbside and/or drop-off paper recycling service. In fact, paper is among the most recycled materials, second only to lead-acid batteries, measured by recovery percentage of generation. Recovering a ton of mixed paper can save up to 166 gallons of gasoline. Recovered paper goes back to mills for processing and provide plants with a cheaper alternative to freshly procured wood. Figure 1.12 shows how steeply the recovery rate in paper and paperboard manufacture has increased over the last four decades. These data were obtained from Howard and Jones (2016).

[2] Accessed via https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_fs.pdf

Figure 1.12. Recovered Paper Consumption Rate in Paper and Paperboard Manufacture (All Grades)

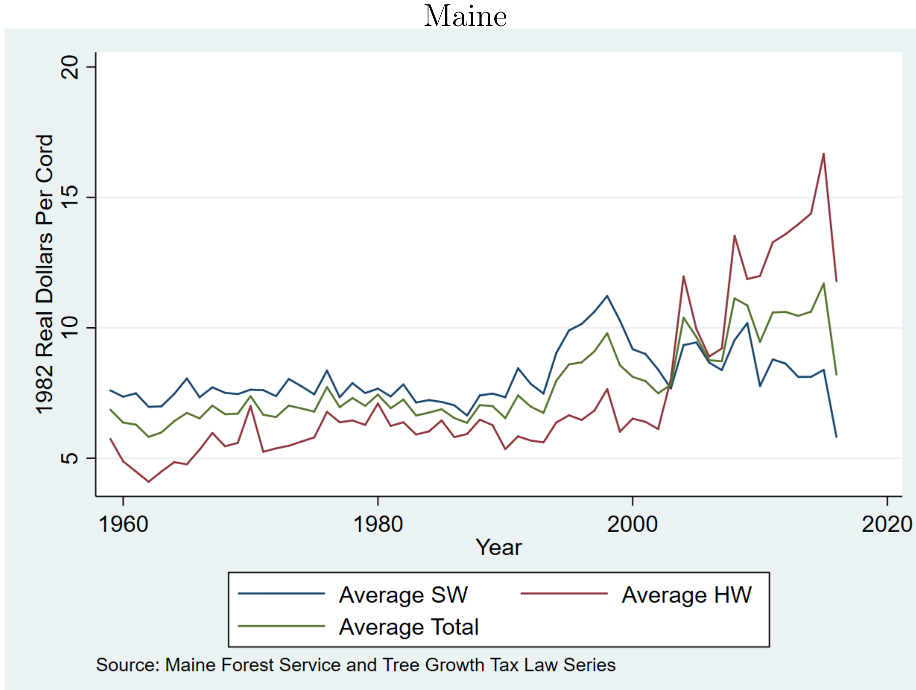


1.3.2.3 Input Supply

From a supply perspective, mills get significantly affected by stumpage and energy prices, since both impact overall harvest and procurement costs. Stumpage prices have historically been relatively stable, except during the last two decades when prices started to increase. In Maine, the average of all hardwood species has seen the highest increase in stumpage value in the past few years. Data on stumpage prices were collected from Maine Forest Service price reports and Tree Growth Tax Law series[3] and are displayed in Figure 1.13.

[3]Compiled by David B. Field, Professor Emeritus of Forest Resources, and Adam Daigneault, Assistant Professor of Forest, Conservation and Recreation Policy, University of Maine

Figure 1.13. Average Softwood (SW) and Hardwood (HW) Real Stumpage Prices in Maine



According to data from the Energy Information Administration (EIA), diesel prices for transportation purposes, displayed in Figure 1.14 have also been increasing. Starting in the early 2000s, diesel prices have spiked up, only shortly interrupted at the end of the decade, mainly due to the financial recession. The average diesel prices for all other purposes has experienced a remarkably similar trend. It is these increments in procurement costs that make recovered materials attractive to mills. However, the U.S. is the largest exporter of recovered paper products to China, while domestic manufacturers juggle with increasing input and energy costs -stimulated by new demand for cardboard and packaging containers which may disappear if online retailers seek alternative materials- and foreign competition. Domestically, prices for paper and board have increased (Figure 1.15), and even more so have prices for wood pulp, but new foreign manufacturing facilities have proved their influence in bringing global paper prices down.

Figure 1.14. Distillate Fuel Oil Price For the Transportation Sector in Maine

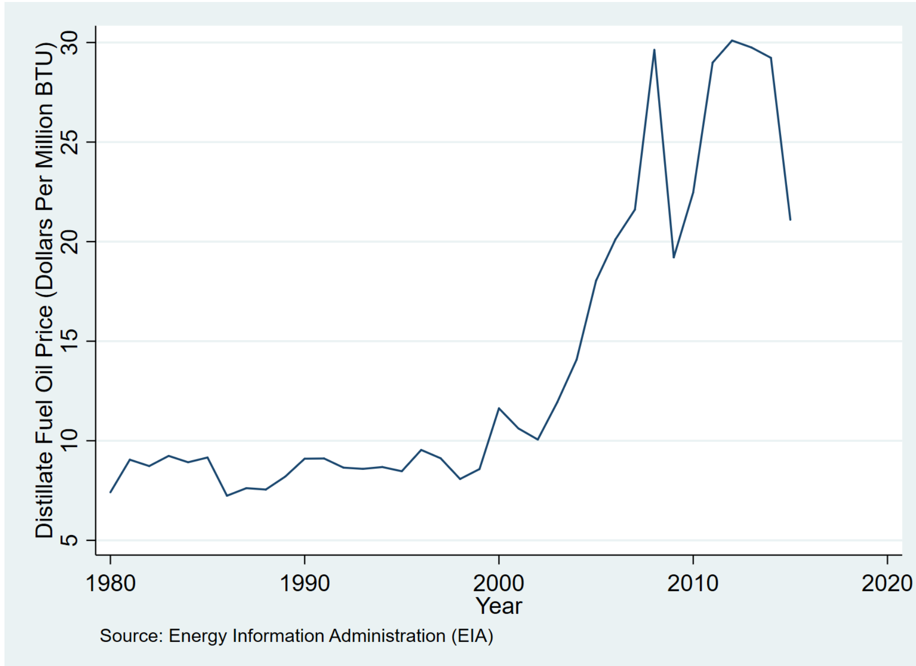


Figure 1.15. Producer Price Indexes for Paper, Board, Wood Pulp and All Products

1.4 Concluding Remarks

The history of the pulp and paper industry in Maine is a story of evolution, progress and adaptation, and will continue to be so if the sector aspires to remain competitive in an ever-changing and increasingly competitive global market. New technologies and sources of demand, and even environmental movements, can be highly beneficial for mills if the incentives are aligned. Today, the industry still contributes largely to the state economy and Maine keeps producing substantial quantities of paper and board products, but several facilities have closed down and deeply affected their towns by going out of business. The next chapters will explore the role of a major environmental regulation on the pulp and paper industry, known as the Cluster Rule, on employment levels, and discuss the feasibility of potential biofuel refineries developments in or around paper mills that have shut down.

CHAPTER 2
ENVIRONMENTAL REGULATIONS AND EMPLOYMENT IN THE PULP AND PAPER INDUSTRY: EVIDENCE FROM THE CLUSTER RULE

2.1 Introduction

Environmental regulations are often believed to affect employment and productivity. In fact, deregulation is frequently announced as an expansionary policy tool with the ability to bolster employment levels. The belief is that abatement costs introduced by regulations increase total production costs and, when transferred to consumers, raise prices, lower demand and reduce employment -or at least do so in a competitive market- while deregulations simply undo this mechanism. However, standard neoclassical micro-economic analysis and evidence from past empirical research do not necessarily support this theory (Becker and Henderson, 2000; Cole and Elliott, 2007; Coglianese, Finkel, Carrigan, 2013; Gray and Shadbegian, 2015; Hafsted and Williams, 2016). Some studies even conclude that abatement can increase productivity and boost employment (Porter and van der Linde, 1995; Berman and Bui, 2001; Morgenstern, Pizer, Shi, 2002), while others find statistically significant employment and productivity losses related to specific air quality regulations (Greenstone, 2002; Greenstone, List, Syverson, 2012). Given the lack of consistent evidence on the effect of regulations on long-term changes in labor demand, it seems ambitious to speculate a priori on the marginal effect of specific environmental regulations on employment.

As discussed in Chapter 1, the pulp and paper industry in the United States has suffered a tremendous decline in employment levels during the last few decades. Additionally, these drastic drops in labor were paralleled by decreasing number of operating plants across the country. Although explanations for this trend abound in the literature, foreign low-cost and subsidized competition, low demand for paper products and high input costs are uniformly pointed out as the main causes of underemployment in the industry (Woodall et al., 2011; Johnston, 2016).

Nevertheless, understanding the drivers of such violent and relatively rapid changes in the paper-making industry should be a continuous and comprehensive effort. On that note, the particularities of the industry, such as its highly pollution-intensive nature, should not be ignored. According to the Pollution Abatement Costs and Expenditures Survey (PACE, 2005[1]), the paper manufacturing industry has one of the highest abatement costs to shipment ratios. While for the average manufacturing plant in the U.S. abatement costs are only 0.4% of the total value of shipments, the ratio of abatement costs to shipments in the paper manufacturing industry is roughly 1%. Other industries with similar ratios include metal manufacturing, chemical manufacturing, and the petroleum and coal products industry.

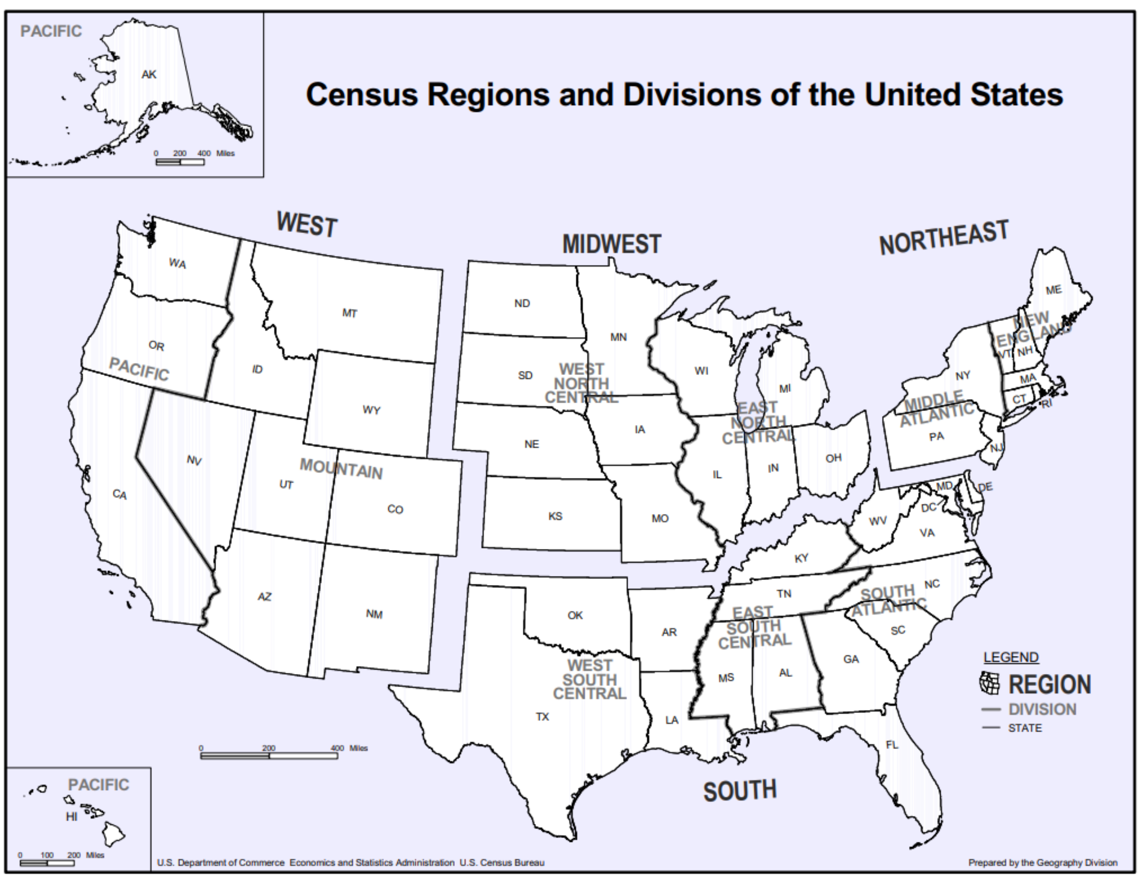
If regulations interfere with the labor market, one would expect highly polluting, highly regulated industries to display symptoms from this interference most apparently. Since the pulp and paper industry is one of these highly polluting industries and it has experienced significant variations in employment levels in the last few decades, this chapter attempts to establish a relationship between environmental regulations and employment in this industry.

Building off from work by Gray et al. (2014) and incorporating supply and input-based data from regional databases, I use a difference-in-differences estimator to analyze the influence of the Cluster Rule, the first integrated, multimedia regulation released by the Environmental Protection Agency (EPA) in 1998, on employment levels at regulated pulp and paper plants relative to employment at

[1]U.S. Census Bureau, *Pollution Abatement Costs and Expenditures: 2005*, MA200(05), U.S. Government Printing Office, Washington, DC, 2008.

non-affected establishments. All analyses are conducted for the entire United States and for the Northeast region separately, following the U.S. Census Bureau Regions and Divisions classification shown in Figure 2.1. Confidential establishment level data were collected from the Annual Survey of Manufacturers and Census of Manufactures at the U.S. Bureau of the Census from 1980 to 2015. Results suggest that mills that employ the polluting processes which the Cluster Rule regulates have, on average, substantially higher employment levels. However, I find strong evidence of net negative impacts from the Cluster Rule on employment at the national level ranging from 17% to 24%, and weaker evidence of a roughly 30% negative effect on Northeastern pulp and paper mills.

Figure 2.1. Census Regions and Divisions



2.1.1 The Cluster Rule

The Cluster Rule (CR) stems from historical impacts of the pulp and paper industry on the environment. In 1982, a flood in Times Beach, Missouri contaminated the town almost in its entirety with dioxin, which is a highly toxic group of chemical compounds that, according to the World Health Organization (WHO), can cause reproductive and developmental problems, damage the immune system, interfere with hormones and also cause cancer[2]. Times Beach was declared uninhabitable by the Centers for Disease Control and Prevention and, in 1983, its residents were relocated. On that same year, the EPA initiated a national dioxin survey and detected consistently elevated levels of dioxins downstream from pulp and paper mills. In response to the flood incident, which substantially increased public perception of the toxicity of dioxins and its danger to human health, the Environmental Defense Fund and the National Wildlife Federation filed lawsuits against the EPA after denial of a petition requesting that all known sources of dioxin pollution be regulated by the agency. This lawsuit required the EPA to propose water regulations by 1993, and the 1990 Clean Air Act Amendments required the agency to set Maximum Achievable Control Technology (MACT) standards for air pollution from the pulp, paper, and paperboard industry by 1997 (Powell, 1999). Considering these requirements, the EPA published the "National Emission Standards for Hazardous Air Pollutants from the Pulp and Paper Industry (subpart S)" and the "Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards: Pulp, Paper, and Paperboard Point Source Category" on April 15, 1998. These guidelines became popularly known as the "Cluster Rule".

The Cluster Rule, coordinated by the Office of Air and Radiation and the Office of Water of the EPA, is the first integrated, multi-media regulation, designed to

[2]In the 1970s, dioxins were identified in the United States as "the most potent animal carcinogen ever tested" (Powell, 1999).

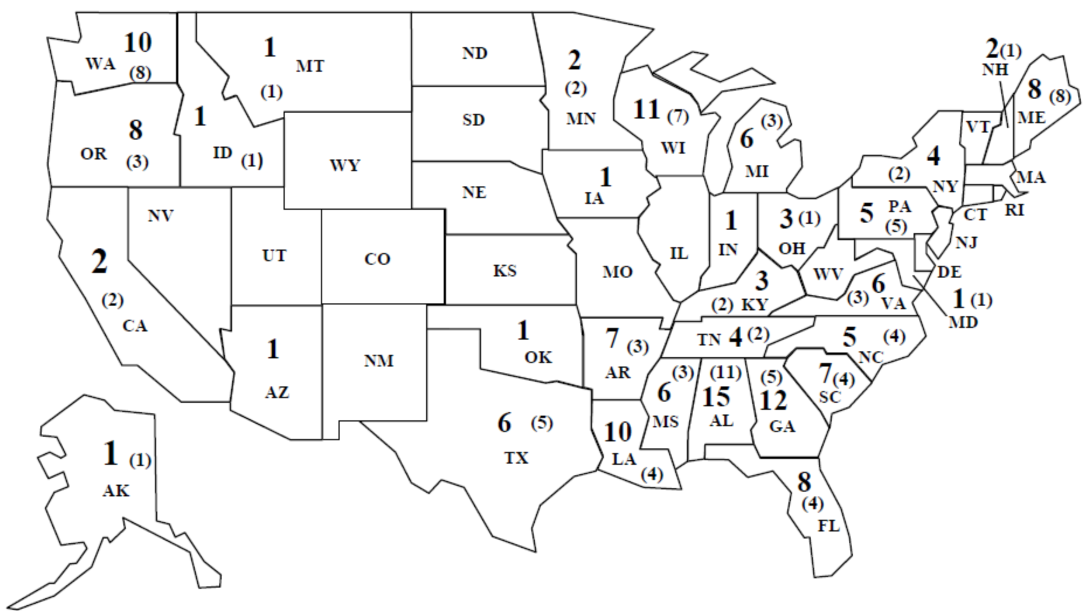
control both air and water pollution from pulp and paper mills. By integrating, or "Clustering", the requirements for mills, plants can select the best combination of controls to reach the rule's targets, aiming to reduce capital equipment costs, and thus alleviating the regulatory burden from abatement costs. The rule was initially proposed on December 17, 1993 and immediately submitted for a public comments period. Paper industry representatives argued that the EPA underestimated compliance costs and, thus, the negative impact the rule was going to have on the entire industry. In response, the agency made substantial changes and released the final rule in 1998 (Powell, 1999). Interestingly, Morgan et al., (2014) found that ex ante capital costs from the EPA related to complying with Cluster Rule requirements were overestimated by 30 to 100% due to "cleaner technology, flexible compliance options, site-specific rules, shutdowns and consolidations".

The Cluster Rule set MACT standards to regulate hazardous air pollutant (HAP) emissions from 155 out of the 565 pulp, paper and paperboard mills in the United States. These facilities generate toxic air emissions from their pulping process, especially those which rely on kraft, semi-chemical, sulfite, or soda processes to chemically pulp wood. Out of those 155 mills, 96 mills were also required to comply with the Best Available Technology (BAT) Economically Achievable Effluent guidelines which established limits for toxic water discharges from mills that combined chlorine bleaching and chemical kraft pulping. These processes are the most pollution-intensive, since they can create chloroform, furan, and dioxin, some of the main targets of the rule (Powell, 1999).

In general, Maximum Achievable Control Technology (MACT) standards are developed by the EPA focusing on the outcome and not the cost. A MACT standard sets the average level of HAP emission control achieved by the top 12% of the sources in a given industry as the minimum level of HAP emission control for the entire industry. On the other hand, Best Available Technology (BAT)

Economically Achievable standards do take into account costs. For the pulp and paper industry, MACT and BAT standards were expected to reduce HAP emissions from plants by 59%, sulfur emissions by 47%, volatile organic compounds by 49%, particulate matter by 37%, dioxin and furan by 96%, and chloroform by 99% (Gray et al., 2014). Figure 2.2 is a map highlighting the number of plants by state which would be subject to Cluster Rule standards in 1995. The number in large font represents MACT-regulated mills and the number in parentheses refers to BAT-regulated mills. This map was obtained from one of the original economic analysis conducted by the EPA and published in 1997 for the Cluster Rule.

Figure 2.2. MACT-Subject Mills and BAT-Subject Mills by State in 1995



Source: EPA (1997). Number of MACT mills shown in large font and BAT mills shown in parentheses.

2.1.2 Literature Review

Few studies have focused on the effect, if any, of the so-called Cluster Rule on employment levels in the pulp and paper industry in the United States, and none have done so centering their analysis on the Northeast or any other specific region.

However, plenty of research has looked at the effect of other types of environmental regulations on employment and, on the greater question of overall environmental regulations and industry performance (measured as employment, productivity, output or growth), the literature is substantially more extensive. Below is a review of some of the relevant studies which motivated and/or informed my research.

Porter and van der Linde (1995) challenged the traditional "trade-off" framework between cost-minimizing firms and environmental regulations. By establishing a link between competitiveness and innovation and, in turn, between innovation and regulation, they argue that "properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them". This idea is now commonly known as the Porter hypothesis. Berman and Bui (2001) concluded that productivity and labor demand in the Los Angeles Air Basin oil refineries increased substantially between 1987 and 1992, a period of sharply increased environmental regulations and low productivity in other regions. Greenstone (2002) focused on the Clean Air Act, which established air quality standards for criteria pollutants and, based on performance on these standards, counties in the U.S. are classified as attainment or non-attainment areas. These designations serve as one of the components which determine the stringency of environmental regulations over polluters in each area. Greenstone, using 1.75 million plant-level observations obtained from the Census of Manufactures, found that non-attainment counties lost 590,000 jobs, $37 billion in capital stock, and $75 billion of output from pollution-intensive industries relative to similar industries in attainment areas. On a similar topic, Becker and Henderson (2000) found that non-attainment areas suffered a 26 to 45 percent decrease in growth of plants during 1963 to 1992 compared to attainment counties.

Morgenstern et al. (2002) examined pulp and paper mills, plastic manufacturers, petroleum refiners, and iron and steel mills -all highly polluting industries- and found that increases in environmental spending do not cause significant changes in employment on these industries. Although small, they even found statistically significant positive effects on employment in the plastic and petroleum industries. Cole and Elliott (2007) pioneered research on this area outside of the United States and found no evidence of a statistical significant "trade-off" between jobs and environmental regulations in the United Kingdom. Greenstone et al. (2012) analyzed 1.2 million plant observations from the Annual Survey of Manufactures from 1972 until 1993 to estimate how total factor productivity at manufacturing plants in the United States were impacted by air quality regulations. Their overall findings suggest that manufacturing plants faced an economic cost of roughly $21 billion, which corresponds with a 4.8 percent decline in total factor productivity and about 8.8 percent of manufacturing profits during the period 1972-1993. Hafstead and Williams (2016) analyzed environmental policy and employment using a general equilibrium two-sector search model and found that both performance standards or pollution taxes do not produce substantial overall net effects on employment, while they found evidence that the latter can cause shifts in employment from regulated to non-regulated industries.

Findings from empirical research are remarkably inconsistent about the direction of the effect of environmental regulations on employment and productivity. Such inconsistency suggests that this effect may vary by factors such as industry, type of regulation, measure of competitiveness, and/or region. On this note, Dechezleprêtre and Sato (2017) provide an extensive review of the literature on this topic, organized in categories based on these factors. A similar review of the literature had also been conducted by Jaffe et al. (1995). Dechezleprêtre and Sato (2017) conclude, as did the study by Jaffe et al. (1995) over 20 years ago, that there is little evidence supporting a large adverse effect on competitiveness from environmental regulations. My research attempts to contribute to this discussion, focusing on a specific environmental regulation, the so-called Cluster Rule, on a specific industry, the pulp and paper industry, and on a specific region, the Northeastern United States.

The most similar study to my research is Gray et al. (2014). Using data from both the Annual Survey of Manufactures and the Census of Manufactures, they developed a difference-in-differences (DiD) estimator to investigate the differential effect from the Cluster Rule on affected and non-affected mills. Their panel dataset included 2593 observations from 214 plants over the period 1993-2007. They measured employment as total number of employees at a plant and also ran their models with alternative measures of employment such as production workers, production worker hours and production worker wages. They also considered alternative Cluster Rule dates since compliance dates varied by plant. Their main findings suggest that BAT mills suffered a 3% to 7% reduction in employment relative to the control group (non-affected plants). BAT plants also had moderately lower employment than MACT mills. They also consistently found positive and statistically significant effects of the Cluster Rule on production worker wages in the order of 5% higher in MACT mills relative to both BAT and control plants.

However, their study only takes a national level approach and includes a limited set of socioeconomic control variables which may affect employment at mills. This chapter will expand the work by Gray et al. (2014) by extending the years considered in their study, examining employment effects both in the U.S. and the Northeast separately, and including a more comprehensive set of control variables in these models.

2.2 Data

Establishment-level data on employment and on variations of it such as number of production workers and total production hours are confidential and only accessible via one of the Federal Statistical Research Data Centers from the Census

Bureau. The Census collects this information from the Annual Survey of Manufactures (ASM) and the Census of Manufacturers[3] (CMF). This research is based on data accessed at the Boston Federal Statistical Research Data Center where ASM and CFM data from 1980 to 2015 were merged with Gray et al.'s (2014) dataset for establishment-level information on Cluster Rule compliance. A Longitudinal Business Database plant identifier was used to identify establishments across datasets. Gray et al. (2014) used EPA's lists of affected plants to accurately create dummy variables for plants covered by the Cluster Rule. In this study, these variables are "Air" which equals unity if the plant's processes make it subject to MACT standards, which target HAP, and "Water" which equals unity if the plant's processes make it subject to BAT standards, which target pollution from water discharges. These dummy variables are consistent throughout the entire dataset for each plant, since they attempt to capture differential effects from employing polluting processes and not from the Cluster Rule itself.

Along with the stringency of the Cluster Rule across mills, effective compliance dates also varied according to plants' characteristics. While most MACT-regulated facilities were required to comply by early 2001, BAT-regulated plants' compliance requirements started at the time of renewal of the National Pollutant Discharge Elimination System permit, which is granted for five years. In light of these observations, MACT98, BAT98, MACT01, BAT01 dummy variables are created to account for the potential four-year period when mills were likely to make the changes in their processes necessary to comply with the rule. These changes are the mechanisms which may affect employment and, hence, precisely what this study aims to identify. Therefore, these dummy variables implicitly create a control group, plants which are not MACT-regulated (and thus also not BAT-regulated since the latter is a proper subset of the MACT group), and a treatment group, conformed by

[3]The Annual Survey of Manufacturers is conducted annually, except for years ending in 2 and 7, when data from the ASM are collected in the manufacturing sector of the Economic Census

plants which are only MACT-regulated or both MACT- and BAT-regulated. These groups allow for a difference-in-differences (DiD) estimator to understand differential effects between regulated and non-regulated groups and within MACT- and BAT-regulated mills. In addition to these Cluster Rule variables, this study includes further plant-specific information.

A "Pulp-Intensity" variable was created as a ratio of a plant's pulp capacity over total pulp and paper capacity. Pulp capacity is used as a proxy for stringency or "intensity" of the rule over plants since the pulping process from integrated mills -facilities which house their own pulping and paper-making manufacturing- is the most polluting operation. In fact, Gray and Shadbegian (2003) established a strong relationship between regulatory stringency and pulping facilities. Thus, the Pulp-Intensity variable is expected to capture differential effects from pulping-intensive plants relative to more evenly integrated ones. Moreover, this analysis includes a pulp dummy variable[4], which equals unity if the plant houses its own pulping facility, a kraft dummy variable, which equals unity if the plant chemically pulps wood using a kraft process, and an "old" dummy variable, which equals unity if the plant operated in 1960 or before. Beyond plant characteristics, models include cost of fuels, cost of materials, and cost of purchased electricity to capture the potential impacts of operating costs on employment. These data were obtained from the ASM and CMF datasets at Census. However, employment is not simply a function of plant-specific information and many exogenous factors may have substantial implications for a plant's demand for labor. On that note, this analysis includes socioeconomic control variables at the county, state and national levels.

These control variables include income, population, unemployment, P&P GDP, paper consumption, recycled paper production, state forestry policy -proxied with

[4]Only included in models where the variable's underlying sample complied with Census Bureau's disclosure guidelines.

Best Management Practices (BMPs) stringency- and stumpage prices. Data on income were obtained from the Bureau of Economic Analysis (BEA) Regional Income Accounts and are measured as average personal income in county in thousands of dollars. Population estimates are measured in absolute number of persons at the county level and P&P GDP is measured as the total contribution of the pulp and paper sector to the state's gross domestic product. Both population and P&P GDP were also obtained from BEA. Unemployment rate was collected from the Bureau of Labor Statistics (BLS) Local Area Unemployment Statistics and is measured as percentage of total civilian labor force unemployed in state. These socioeconomic variables are expected to capture the impact that labor supply changes may have on mills' employment levels.

The United States Department of Agriculture (USDA) U.S. Timber, Production, Trade, Consumption, and Price Statistics, 1965-2013[5] (Howard and Jones, 2016) was used to obtain data on total paper and board consumption in thousands tons and total recovery rate of paper consumption in paper and paperboard manufacture in thousand short tons. Paper consumption is a net estimate, which takes into account forgone consumption from exports of paper and additional consumption from imports, and the recovery rate is the ratio of total recovered paper collected to new supply of paper and paperboard. Both paper consumption and recovery rate are reported at the national level. These variables attempt to control for one of the reasons for the downfall of the pulp and paper industry in the U.S., which is the decline in demand for paper related to the shift towards the digital era and the increased supply of paper from foreign competition. Additionally, the recovery rate variable, which introduces information on recycling levels, is expected to capture changes in employment at pulp mills related to switching from processing wood pulp to recovered paper feedstock. Implicitly, this variable may also introduce

[5] 2014 and 2015 values were calculated using a simple weighted average.

information on changes in paper demand related to consumers' attitudes towards environmental issues such as deforestation.

The last set of control variables are related to mills' input costs. BMPs is a dummy variable which equals unity starting on the year when the state released a manual on forestry Best Management Practices, which are widely believed to increase harvest costs that ultimately get transferred to mills (Sun, 2006). These data on BMP manuals were obtained from Cristan et al. (2018) and only refer to the existence of a manual, without regard to variations in implementation or enforcement of these practices across states. Lastly, the USDA report above also provides data on pulpwood stumpage prices in current dollars per cord for two species in Louisiana and two other species in northern New Hampshire. Since these values are relatively representative of stumpage prices in their respective regions, the average of both species is used for Southern and Northern plants. Table 2.1 provides description and source data for all variables and summary statistics from both the entire United States and the Northeast samples are reported in Table 2.2

Table 2.1. Variable Description and Source

Variable	Description	Source
Employment	Average employment at plant	Census
Production Workers	Average production workers at plant	Census
Production Hours	Annual production hours at plant in thousands	Census
Air	Dummy variable = 1 if plant's processes fall under MACT standards	Gray et al. (2014)
Water	Dummy variable = 1 if plant's processes fall under BAT standards	Gray et al. (2014)
MACT98	Dummy variable = 1 after 1997 if plant is covered by MACT standards	Gray et al. (2014)
BAT98	Dummy variable = 1 after 1997 if plant is covered by BAT standards	Gray et al. (2014)
MACT01	Dummy variable = 1 after 2000 if plant is covered by MACT standards	Gray et al. (2014)
BAT01	Dummy variable = 1 after 2000 if plant is covered by MACT standards	Gray et al. (2014)
Old	Dummy variable = 1 if plant was operational in 1960	Census
Pulp	Dummy variable = 1 if plant is a pulp mill	Census
Pulp-Intensity	Ratio of pulp capacity over total pulp and paper capacity combined	Census
Kraft	Dummy variable = 1 if plant chemically pulps wood using a kraft process	Census
Cost of Fuels	Annual cost of fuels consumed for heat and power by plant in thousands of dollars	Census
Cost of Materials	Annuals cost of all operating materials and supplies put into production by plant in thousand fo dollars	Census
Cost of Purchased Electricity	Annual cost of electricity purchased for heat and power by plant in thousands of dollars	Census
Income	Average personal income in county in thousands of dollars	BEA
Population	Total number of persons in county	BEA
Unemployment Rate	Percentage of civilians in the labor force unemployed in state	BLS
P&P Share of GDP	Pulp and paper industry contribution to Gross State Product in millions of current dollars	BEA
Paper Consumption	Paper and paper board consumption in thousand tons in the US	Howard and Jones (2016)
Recovery Rate	Ratio of recovered paper to total new supply in the US	Howard and Jones (2016)
Forestry BMPs	Dummy variable = 1 starting on the year when state published a BMP manual	Cristan et al. (2017)
Stumpage Prices	Average stumpage prices from Southern and Northern species in current dollars per cord	Howard and Jones (2016)

Table 2.2. Summary Statistics

Variables	**National Sample**		**Northeast Sample**	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Outcome Variables				
Employment	656.6	452.7	752.9	494.7
Production Workers	513.2	355.3	584.2	389.2
Production Hours	1097	757.9	1261	820.8
Ln(Employment)	6.241	0.7601	6.411	0.6848
Ln(Production Workers)	5.992	0.7662	6.157	0.6828
Ln(Production Hours)	6.751	0.7685	6.926	0.6901
Cluster Rule Variables				
Air	0.6571	0.4747	0.5487	0.4979
Water	0.4486	0.4974	0.485	0.5001
MACT98	0.3778	0.4849	0.25	0.4333
BAT98	0.2402	0.4273	0.2313	0.4219
MACT01	0.3046	0.4603	0.1963	0.3974
BAT01	0.1933	0.395	0.185	0.3885
Plant-Specific Controls				
Old	0.7495	0.4334	0.7662	0.4235
Pulp	0.8621	0.3448	0.8848	0.3195
Pulp-Int	0.3599	0.2995	0.2801	0.2972
Kraft	0.5709	0.495	0.3186	0.4663
Cost of Fuels	1.50E+004	1.31E+004	1.52E+004	1.65E+004
Cost of Materials	1.34E+005	1.04E+005	1.30E+005	1.49E+005
Cost of Purchased Electricity	9710	9890	7420	8263
Socioeconomic Controls				
Income	5.50E+006	1.96E+007	3.90E+006	6.12E+006
Ln(Income)	14.3	1.338	14.42	1.159
Population	2.28E+005	8.62E+005	1.44E+005	1.74E+005
Unemployment Rate	6.227	1.992	5.982	1.682
P&P Share of GDP	1.412	1.195	1.904	1.89
Paper Consumption	8.99E+004	1.12E+004	8.79E+004	1.17E+004
Paper Recovery	45.55	12.21	43.3	12.78
Forestry BMPs	0.2345	0.4237	0.2712	0.4449
Stumpage Prices	12.32	7.549	6.399	2.867

2.3 Methods

In order to capture differential effects on pulp and paper industry employment from regulated mills relative to non-regulated facilities, I use a difference-in-differences (DiD) estimator. The baseline specification is as follows:

$$lnEmp_{py} = \beta_0 + \beta_1 * Air_p + \beta_2 * Water_p + \beta_3 * MACT\_CRYear_{py} + \beta_4 * BAT\_CRYear_{py} + \omega_s + \gamma_y + \mu_{py} \quad (2.1)$$

In Equation 2.1, the outcome variable Emp is a measure of employment, such as total employment or number of production workers or total production hours, in log form. The Cluster Rule dummy variables, and its variations, were discussed in the data section. ω_s is a vector of state dummy variables, γ_y is a vector of year dummy variables, μ is the error term, and p indexes plants and y indexes years. Equation 2.2 is an expansion of the baseline specification, where Z_{py} is a series of plant-specific control variables and local or national socioeconomic control variables.

$$lnEmp_{py} = \beta_0 + \beta_1 * Air_p + \beta_2 * Water_p + \beta_3 * MACT\_CRYear_{py} + \beta_4 * BAT\_CRYear_{py} + \theta * Z_{py} + \omega_s + \gamma_y + \mu_{py} \quad (2.2)$$

These specifications are used in three models: Ordinary Least Squares (OLS) regressions, robust OLS regressions, and robust plant-fixed-effect estimations. All models were run using promulgation year dummies only (MACT98 and BAT98), effective compliance year dummies only (MACT01 and BAT01) and both. Given these specifications, the $MACT * CRYear$ variable returns the impact of the Cluster Rule on the treatment group relative to the control group. The variable $BAT * CRYear$ returns differential effects between only MACT-regulated mills and both MACT- and BAT-regulated plants. Thus, the differential effect between BAT mills and the control group is the cumulative effect from β_3 and β_4, since BAT mills are a proper subset of the MACT group.

2.4 Results and Discussion

Baseline models are OLS regressions which include Cluster Rule variables and state and year dummies. Tables 2.3 and 2.4 contain results from these models over the national and regional samples using total employment, production workers and production hours as the outcome variables. For the national models, both the Air and $Water$ variables returned statistically significant and positive coefficients, suggesting approximately 1% higher in employment in air-polluting (or MACT-subject) mills, and roughly 60% higher employment in water-polluting (or BAT-subject) mills relative to MACT-subject mills. In the Northeast, findings suggest that air-polluting mills have around 95% lower employment, while BAT-subject mills more than offset this effect with close to 115% higher employment. Thus, the impact of being subject to MACT standards is highly detrimental for employment in Northeastern mills, while being subject to both MACT and BAT standards yields a net positive employment effect. Coefficients are remarkably similar across the promulgation and compliance date models and over the three dependent variables used. It is important to point out that these are not changes attributable to the Cluster Rule itself, but to the polluting processes which the rule regulates. Direct Cluster Rule impacts are those reported by the interactions between $MACT$ and BAT and the different years.

Table 2.3. Baseline Models - United States

Variable	Total Employment			Production Workers			Production Hours		
Air	0.08945*	0.09925**	0.08902*	0.08927*	0.09815**	0.08895*	0.07701	0.08638*	0.07658
	(0.03962)	(0.03503)	(0.03962)	(0.04032)	(0.03565)	(0.04032)	(0.04054)	(0.03584)	(0.04054)
Water	0.6245***	0.6094***	0.6250***	0.6137***	0.5997***	0.6140***	0.6130***	0.6006***	0.6134***
	(0.03770)	(0.03286)	(0.03769)	(0.03836)	(0.03345)	(0.03837)	(0.03857)	(0.03363)	(0.03857)
MACT98	0.08478		0.03277	0.06890		0.02918	0.08997		0.03401
	(0.04850)		(0.07668)	(0.04935)		(0.07804)	(0.04962)		(0.07846)
BAT98	-0.1747***		-0.06310	-0.1392**		-0.05791	-0.1489**		-0.05113
	(0.04600)		(0.07271)	(0.04682)		(0.07400)	(0.04707)		(0.07440)
MACT01		0.08660	0.06405		0.06898	0.04899		0.09351	0.06935
		(0.04732)	(0.07496)		(0.04816)	(0.07629)		(0.04841)	(0.07670)
BAT01		-0.1862***	-0.1388*		-0.1447**	-0.1011		-0.1597***	-0.1216
		(0.04425)	(0.07004)		(0.04504)	(0.07129)		(0.04529)	(0.07168)
Adjusted R^2	0.4402	0.4406	0.4404	0.4296	0.4298	0.4296	0.4268	0.4271	0.4269
Observations†	4900	4900	4900	4900	4900	4900	4900	4900	4900

All regressions include state and year dummies and a constant - Standard errors in parentheses

†Rounded to nearest hundredth - *p<0.05 **p<0.01 ***p<0.001

Table 2.4. Baseline Models - Northeast Region

Variable	Total Employment			Production Workers			Production Hours		
Air	-0.9271***	-0.9431***	-0.9227***	-0.9657***	-0.9849***	-0.9594***	-1.0637***	-1.0784***	-1.0599***
	(0.1224)	(0.1180)	(0.1233)	(0.1250)	(0.1205)	(0.1259)	(0.1251)	(0.1206)	(0.1261)
Water	1.1214***	1.1450***	1.1166***	1.1286***	1.1528***	1.1221***	1.2147***	1.2401***	1.2105***
	(0.1234)	(0.1192)	(0.1243)	(0.1261)	(0.1218)	(0.1270)	(0.1262)	(0.1219)	(0.1271)
MACT98	-0.05769		-0.1450	-0.07528		-0.1790	-0.05379		-0.1335
	(0.1739)		(0.2420)	(0.1776)		(0.2471)	(0.1778)		(0.2474)
BAT98	0.1968		0.1958	0.1870		0.2125	0.2109		0.2029
	(0.1725)		(0.2415)	(0.1762)		(0.2466)	(0.1764)		(0.2469)
MACT01		0.01077	0.1357		0.01433	0.1679		0.006533	0.1221
		(0.2142)	(0.2972)		(0.2188)	(0.3035)		(0.2190)	(0.3038)
BAT01		0.1445	-0.02283		0.1139	-0.06782		0.1634	-0.01001
		(0.2129)	(0.2968)		(0.2175)	(0.3031)		(0.2177)	(0.3035)
Adjusted R^2	0.4520	0.4521	0.4512	0.4253	0.4253	0.4243	0.4361	0.4360	0.4351
Observations†	800	800	800	800	800	800	800	800	800

All regressions include state and year dummies and a constant - Standard errors in parentheses

†Rounded to nearest hundredth - *$p<0.05$ **$p<0.01$ ***$p<0.001$

Findings from these interactions from the national sample show that MACT standards did not have a statistically significant impact on employment or any other outcome variable on either the rule promulgation date or the effective compliance date. On the other hand, BAT standards did have a negative statistical significant effect whose magnitude ranged from approximately an 18% decrease in total employment, a roughly 14% decrease in production workers, and around a 15% decline in production hours. Interestingly, none of these models returned a statistically significant effect different from zero for any post-CR variables in the Northeast, suggesting that the rule itself did not affect Northeastern mills.

The baseline models do not control for factors which are likely to affect employment at mills (such as the plant-specific and socioeconomic control variables previously discussed above) beyond some region-specific and time-specific variation captured by the state and year dummy variables. Additionally, the assignment of statistical significance can be compromised in the presence of heteroskedasticity. The following models remedy these potential threats to identification by including a comprehensive set of control variables, and using heteroskedasticity-robust and plant fixed effect estimators. Tables 2.5 and 2.6 report results from robust models with control variables and Tables 2.7 and 2.8 present results from robust plant fixed effect models with controls. A discussion of these results follows below.

Table 2.5. Robust Estimation with Controls - United States

Variable	Total Employment			Production Workers			Production Hours		
Air	-0.05153	0.009585	-0.05224	-0.04346	0.01411	-0.04399	-0.06163	-0.01168	-0.06228
	(0.03704)	(0.03220)	(0.03703)	(0.03894)	(0.03335)	(0.03893)	(0.03940)	(0.03366)	(0.03939)
Water	0.4023***	0.3384***	0.4025***	0.3888***	0.3274***	0.3889***	0.3890***	0.3339***	0.3892***
	(0.02895)	(0.02361)	(0.02898)	(0.03184)	(0.02527)	(0.03187)	(0.03161)	(0.02530)	(0.03164)
MACT98	0.1197**		0.1675***	0.1080**		0.1549**	0.09927*		0.1312*
	(0.03663)		(0.04870)	(0.04059)		(0.05295)	(0.04005)		(0.05211)
BAT98	-0.2629***		-0.1799***	-0.2376***		-0.1737***	-0.2328***		-0.1583***
	(0.03285)		(0.04379)	(0.03607)		(0.04679)	(0.03602)		(0.04738)
MACT01		0.03923	-0.06562		0.03242	-0.06374		0.03565	-0.04454
		(0.03414)	(0.04500)		(0.03765)	(0.04893)		(0.03686)	(0.04760)
BAT01		-0.2189***	-0.1041**		-0.1915***	-0.08015*		-0.1955***	-0.09341*
		(0.02933)	(0.03870)		(0.03146)	(0.04026)		(0.03176)	(0.04150)
Cost of Fuels	0.000007469***	0.000007618***	0.000007595***	0.000007328***	0.000007463***	0.000007436***	0.000007549***	0.000007681***	0.000007650***
	(0.000001146)	(0.000001146)	(0.000001144)	(0.000001167)	(0.000001168)	(0.000001166)	(0.000001187)	(0.000001189)	(0.000001187)
Cost of Materials	0.000004059***	0.000004055***	0.000004054***	0.000004181***	0.000004177***	0.000004178***	0.000004127***	0.000004122***	0.000004124***
	(1.493e-07)	(1.493e-07)	(1.489e-07)	(1.513e-07)	(1.514e-07)	(1.510e-07)	(1.558e-07)	(1.560e-07)	(1.555e-07)
Cost of Purch. Electricity	4.965e-07	5.345e-07	5.197e-07	-4.822e-07	-4.443e-07	-4.617e-07	1.949e-07	2.336e-07	2.130e-07
	(7.965e-07)	(7.907e-07)	(7.924e-07)	(8.238e-07)	(8.194e-07)	(8.212e-07)	(8.471e-07)	(8.436e-07)	(8.452e-07)
Old	0.2103***	0.2100***	0.2103***	0.2375***	0.2373***	0.2375***	0.2184***	0.2182***	0.2184***
	(0.01672)	(0.01670)	(0.01667)	(0.01796)	(0.01792)	(0.01790)	(0.01781)	(0.01778)	(0.01776)
Ln(Income)	0.01936**	0.01872**	0.01889**	0.01718*	0.01667*	0.01681*	0.01658*	0.01607*	0.01617*
	(0.006568)	(0.006578)	(0.006534)	(0.006996)	(0.007006)	(0.006969)	(0.007026)	(0.007027)	(0.006997)
Population	1.135e-09	1.260e-09	1.068e-09	-1.849e-09	-1.766e-09	-1.927e-09	-3.985e-09	-3.907e-09	-4.017e-09
	(1.150e-08)	(1.156e-08)	(1.144e-08)	(1.176e-08)	(1.182e-08)	(1.173e-08)	(1.204e-08)	(1.206e-08)	(1.198e-08)
Pulp	0.2292***	0.2266***	0.2276***	0.2501***	0.2477***	0.2486***	0.2141***	0.2120***	0.2128***
	(0.02549)	(0.02544)	(0.02537)	(0.02778)	(0.02777)	(0.02770)	(0.02707)	(0.02706)	(0.02700)
Pulp-Intensity	-0.1669***	-0.1633***	-0.1642***	-0.1795***	-0.1766***	-0.1773***	-0.1586***	-0.1560***	-0.1564***
	(0.04357)	(0.04413)	(0.04364)	(0.04627)	(0.04683)	(0.04634)	(0.04683)	(0.04728)	(0.04687)
Kraft	0.2480***	0.2437***	0.2471***	0.2346***	0.2307***	0.2339***	0.2434***	0.2399***	0.2426***
	(0.02023)	(0.02020)	(0.02020)	(0.02130)	(0.02125)	(0.02126)	(0.02158)	(0.02152)	(0.02153)
Unemployment Rate	0.01204*	0.01170	0.01187	0.01348*	0.01322*	0.01335*	0.006924	0.006670	0.006757
	(0.006065)	(0.006063)	(0.006060)	(0.006280)	(0.006280)	(0.006279)	(0.006463)	(0.006458)	(0.006460)
P&P Share of GDP	0.09587***	0.09769***	0.09821***	0.09924***	0.1010***	0.1014***	0.1094***	0.1109***	0.1111***
	(0.01702)	(0.01711)	(0.01711)	(0.01738)	(0.01750)	(0.01749)	(0.01764)	(0.01774)	(0.01775)
US Paper Consumption	-0.0001175*	-0.0001176*	-0.0001180*	-0.0001151*	-0.0001152*	-0.0001156*	-0.0001131*	-0.0001132*	-0.0001135*
	(0.00005422)	(0.00005414)	(0.00005408)	(0.00005481)	(0.00005472)	(0.00005467)	(0.00005745)	(0.00005723)	(0.00005724)
Recovery Rate	0.02895	0.02962	0.02984	0.02784	0.02846	0.02865	0.02743	0.02798	0.02811
	(0.02221)	(0.02220)	(0.02217)	(0.02241)	(0.02239)	(0.02237)	(0.02353)	(0.02346)	(0.02346)
BMP	-0.03908	-0.03390	-0.03572	-0.03625	-0.03166	-0.03339	-0.009651	-0.005399	-0.006934
	(0.02414)	(0.02418)	(0.02418)	(0.02609)	(0.02617)	(0.02618)	(0.02604)	(0.02617)	(0.02618)
Stumpage	-0.01675***	-0.01650***	-0.01706***	-0.01744***	-0.01722***	-0.01771***	-0.01609***	-0.01596***	-0.01633***
	(0.002265)	(0.002199)	(0.002278)	(0.002356)	(0.002300)	(0.002370)	(0.002368)	(0.002304)	(0.002382)
Adjusted R^2	0.7654	0.7655	0.7662	0.7469	0.7468	0.7474	0.7406	0.7406	0.7412
Observations†	3900	3900	3900	3900	3900	3900	3900	3900	3900

All regressions include state and year dummies and a constant - Standard errors in parentheses

†Rounded to nearest hundredth - *p<0.05 **p<0.01 ***p<0.001

Table 2.6. Robust Estimation with Controls - Northeast Region

Variable	Total Employment			Production Workers			Production Hours		
Air	0.1178	0.08609	0.1150	0.04596	0.01342	0.04448	-0.04788	-0.07688	-0.05184
	(0.1087)	(0.1091)	(0.1100)	(0.1136)	(0.1144)	(0.1153)	(0.1123)	(0.1127)	(0.1140)
Water	0.6840***	0.6900***	0.6834***	0.6995***	0.7043***	0.6976***	0.7900***	0.7951***	0.7902***
	(0.06050)	(0.06070)	(0.06146)	(0.06149)	(0.06182)	(0.06220)	(0.06523)	(0.06633)	(0.06707)
MACT98	-0.1969**		-0.1801**	-0.1971*		-0.1933**	-0.1816*		-0.1552*
	(0.07481)		(0.05871)	(0.07766)		(0.06144)	(0.09164)		(0.06202)
BAT98	-0.006412		0.04731	-0.03531		0.04859	-0.002349		0.03520
	(0.07036)		(0.06482)	(0.07194)		(0.06201)	(0.08576)		(0.06572)
MACT01		-0.1642	-0.01441		-0.1471	0.01362		-0.1629	-0.03385
		(0.1153)	(0.1190)		(0.1195)	(0.1252)		(0.1482)	(0.1512)
BAT01		-0.03989	-0.08004		-0.08981	-0.1311		-0.02205	-0.05195
		(0.1103)	(0.1207)		(0.1131)	(0.1224)		(0.1419)	(0.1500)
Cost of Fuels	5.733e-07	8.386e-07	7.422e-07	6.779e-07	9.939e-07	8.877e-07	0.000001373	0.000001617	0.000001527
	(0.000001692)	(0.000001741)	(0.000001738)	(0.000001675)	(0.000001741)	(0.000001737)	(0.000001855)	(0.000001913)	(0.000001912)
Cost of Materials	0.000004229***	0.000004195***	0.000004210***	0.000004373***	0.000004331***	0.000004348***	0.000004245***	0.000004214***	0.000004228***
	(3.639e-07)	(3.658e-07)	(3.659e-07)	(3.692e-07)	(3.717e-07)	(3.718e-07)	(3.904e-07)	(3.935e-07)	(3.939e-07)
Cost of Purch. Electricity	-0.000005982**	-0.000005913**	-0.000005820**	-0.000007528***	-0.000007405***	-0.000007305***	-0.000007344***	-0.000007293**	-0.000007211**
	(0.000002085)	(0.000002101)	(0.000002097)	(0.000002172)	(0.000002188)	(0.000002182)	(0.000002220)	(0.000002257)	(0.000002248)
Old	0.6329***	0.6318***	0.6329***	0.6448***	0.6438***	0.6450***	0.6206***	0.6195***	0.6205***
	(0.03936)	(0.03911)	(0.03910)	(0.04060)	(0.04015)	(0.04018)	(0.04175)	(0.04143)	(0.04149)
Ln(Income)	0.3155***	0.3162***	0.3153***	0.3198***	0.3205***	0.3195***	0.3056***	0.3064***	0.3055***
	(0.05070)	(0.05075)	(0.05065)	(0.05245)	(0.05247)	(0.05235)	(0.05335)	(0.05343)	(0.05331)
Population	-0.000001165**	-0.000001176**	-0.000001167**	-0.000001265**	-0.000001276**	-0.000001267**	-0.000001364***	-0.000001375***	-0.000001368***
	(3.896e-07)	(3.930e-07)	(3.897e-07)	(3.968e-07)	(4.005e-07)	(3.966e-07)	(4.121e-07)	(4.155e-07)	(4.123e-07)
Pulp-Intensity	-1.2404***	-1.2301***	-1.2325***	-1.1933***	-1.1825***	-1.1851***	-1.2095***	-1.1989***	-1.2011***
	(0.1745)	(0.1759)	(0.1754)	(0.1698)	(0.1709)	(0.1705)	(0.1728)	(0.1737)	(0.1736)
Kraft	0.1800***	0.1786***	0.1790***	0.1694***	0.1678***	0.1683***	0.1784***	0.1770***	0.1774***
	(0.04663)	(0.04650)	(0.04664)	(0.04522)	(0.04507)	(0.04515)	(0.04647)	(0.04628)	(0.04639)
Unemployment Rate	0.03412	0.03289	0.03410	0.01019	0.008686	0.009963	0.006355	0.005480	0.006469
	(0.02489)	(0.02474)	(0.02503)	(0.02394)	(0.02385)	(0.02409)	(0.02424)	(0.02418)	(0.02440)
P&P Share of GDP	0.1446***	0.1445***	0.1445***	0.1369***	0.1367***	0.1367***	0.1604***	0.1605***	0.1605***
	(0.02068)	(0.02079)	(0.02075)	(0.02070)	(0.02079)	(0.02075)	(0.02198)	(0.02208)	(0.02207)
US Paper Consumption	0.00003636	0.00003388	0.00003540	-0.00001195	-0.00001503	-0.00001342	-0.000008258	-0.00001019	-0.000008941
	(0.00009089)	(0.00009099)	(0.00009130)	(0.00008378)	(0.00008371)	(0.00008406)	(0.00008241)	(0.00008220)	(0.00008251)
Recovery Rate	-0.04049	-0.03983	-0.03980	-0.02031	-0.01941	-0.01936	-0.02153	-0.02102	-0.02096
	(0.03628)	(0.03637)	(0.03650)	(0.03323)	(0.03327)	(0.03341)	(0.03245)	(0.03242)	(0.03254)
BMP	-0.1381*	-0.1285*	-0.1356*	-0.1498*	-0.1385*	-0.1462*	-0.07860	-0.07039	-0.07674
	(0.05940)	(0.05982)	(0.05972)	(0.06477)	(0.06532)	(0.06528)	(0.07098)	(0.07121)	(0.07141)
Stumpage	-0.7762	-0.7620	-0.7722	-0.2217	-0.2040	-0.2147	-0.07359	-0.06317	-0.07125
	(0.7122)	(0.7114)	(0.7134)	(0.6295)	(0.6306)	(0.6332)	(0.6487)	(0.6461)	(0.6488)
Adjusted R^2	0.7737	0.7730	0.7734	0.7799	0.7792	0.7799	0.7620	0.7614	0.7615
Observations†	700	700	700	700	700	700	700	700	700

All regressions include state and year dummies and a constant - Standard errors in parentheses

†Rounded to nearest hundredth - *p<0.05 **p<0.01 ***p<0.001

Across outcome variables within the national models with robust estimators and control variables (but not fixed effects) reported in Table 2.5, air-polluting mills did not display a statistically significant difference from their counterparts, but water-polluting plants returned, on average, 38% lower employment, 36% lower production workers and 36% less production hours relative to MACT-subject mills and from the control group (since air-polluting plants had no different effect from the control). Additionally, the models within this specification are the only to return statistically significant results for both MACT and BAT standards post Cluster Rule years. In these cases, the net effect of the Cluster Rule relative to the control group is the cumulative result of both coefficients, and despite these models returning coefficients opposite in sign, the negative impact from BAT standards tends to be nearly twice as large as the gains in employment. Specifically, at the promulgation date, MACT standards were related to higher employment in mills by close to 12%, suggesting that MACT-only mills experienced higher employment due to the Cluster Rule than the control group. However, mills that were also BAT-covered experienced over a 26% decrease in employment relative to MACT-mills, which implies that these plants suffered 15% lower employment than non-regulated mills. These effects were smaller but followed similar trends in production workers and production hours, with a 10% increase for MACT-covered mills and a 23% decline for BAT-regulated plants, leaving a total CR effect for BAT mills relative to the control group of roughly 13% lower production workers and hours.

In the post effective compliance years (after 2000) models, only BAT-covered mills returned statistically significant effects. The effects were over a 21% and 19% decline for total employment and for production workers and hours, respectively. When including all post-CR years, MACT-covered mills only experienced a positive effect immediately after the rule's promulgation while BAT-regulated plants experienced continuous negative effects. Specifically, the net impacts of the Cluster

Rule over all years for BAT-mills were roughly a 16% decline in employment and production hours and 10% lower production workers than non-regulated mills. On the other hand, Northeastern mills have experienced different impacts, which are reported in Table 2.6.

First, water-polluting Northeastern mills have, on average, over 68% higher employment, close to 70% higher numbers of production workers, and roughly 79% higher production hours than both air-polluting plants and the control group. Interestingly, these mills did not display statistically significant positive effects in any model. In fact, the impact of the post-CR variables on the various outcome variables are consistently negative, although somewhat weaker. No statistically significant effect was obtained from any variable besides $MACT * 98$. This effect was, on average, close to a 19% decline in total employment and production workers, suggesting that non-production employment was virtually unaffected. Additionally, MACT-regulated mills at the time of promulgation experienced, on average, over 16% lower levels of production hours. Although not the focus of this study, results from some control variables, both at the national and regional levels, are worth pointing out.

At the national level, only the cost of materials and cost of fuels variables were statistically significant, but the magnitude of their positive coefficients were negligible. In other words, these results consistently suggest that a $1000 increase in cost of any of these two variables would increase employment by less than $1/1000$ of a percentage point. In the Northeast, only cost of materials and cost of electricity were relevant, with positive and negative impacts, respectively, but similar trivial magnitudes as in the national models. In the U.S., plants which were operational in 1960 or before have, on average, over 21% higher total employment levels, over 23% more production workers, and roughly 22% higher numbers of production hours. A similar effect stems from pulp mills relative to exclusively paper mills. In the

Northeast, plant's age had a much more substantial effect since, on average, old mills have over 63% higher employment levels, approximately 64% more production workers, and about 62% more production hours. This difference in magnitude of impacts across regions is remarkable, especially since both samples had comparable percentages of old mills (close to 75% at the national level and just over 76% in the Northeast) and implies that historical Northeastern mills tend to be the largest facilities.

The pulp-intensity variable yielded highly statistically significant results in all models. CR-regulated pulp-intensive mills suffered a 16% lower employment level, 17% lower production workers and 15% lower production hours at the national level. This effect was considerably more pronounced in the Northeastern models, with effects closer to or even higher than 120%. This, in part, may be due to the exclusion of the pulp mill dummy variable from these models, which did not conform to disclosure guidelines from the Census Bureau. Across the nation, plants which chemically pulp wood using kraft processes are related to higher employment, production workers and production hours by, on average, 24%, 23% and 24%, respectively. These effects are roughly 18%, 16% and 17%, respectively, at Northeastern plants.

Perhaps intuitively, some of the socioeconomic control variables measured at the national level were only statistically significant in the national level models while some more localized variables were only relevant in the models for Northeastern plants. For example, U.S. paper consumption was only statistically significant at the 95% confidence level in national models, with negative effects which were mere small fractions of a percentage point. Stumpage prices were also relevant only at the national level, and were related to close to 17% lower employment and production workers, and 16% lower production hours. On the other hand, population at the county level was only significant in the models from the Northeast sample, although its minor magnitude is comparable to that of the cost variables. BMPs, measured at the state level, was also significant only in the Northeastern models and related to roughly a 13% lower total employment and production workers with no impact on production hours.

Unemployment rate was only statistically significant at the 95% level in few of the national models, with just over a 1% higher employment and production workers impact. Two highly statistically significant variables in both regions were Ln(Income) and P&P Share of GDP. Percentage points increments in income at the county level were related to over 30% increments in total employment, production workers and production hours at mills across the Northeast. At the national level, however, this effect was much smaller, ranging only in the neighborhood of 2 percentage points. Nationally, plants in states with higher contributions of the pulp and paper industry to the gross state product had almost 10% higher employment, numbers of production workers and production hours. These effects were larger for mills in these types of states in the Northeast, with roughly 14% higher total employment and production workers employment, and a 16% higher level of production hours. Lastly, no statistically significant effect different from zero was obtained from the recovered paper variable from any model.

Table 2.7. Robust Fixed Effect Estimation with Controls - United States

	Total Employment			Production Workers			Production Hours		
MACT98	0.07476		0.1372	0.06147		0.1255	0.06312		0.1093
	(0.09026)		(0.07467)	(0.09161)		(0.07311)	(0.08618)		(0.06787)
BAT98	-0.2407**		-0.1636*	-0.2172**		-0.1590*	-0.2182**		-0.1500*
	(0.08069)		(0.06746)	(0.07878)		(0.06393)	(0.07266)		(0.05854)
MACT01		-0.02197	-0.09024		-0.03039	-0.09149		-0.01563	-0.06719
		(0.08252)	(0.06478)		(0.08652)	(0.06832)		(0.08382)	(0.06821)
BAT01		-0.1897**	-0.1017		-0.1630*	-0.07686		-0.1720*	-0.08996
		(0.07033)	(0.05508)		(0.07103)	(0.05691)		(0.06757)	(0.05656)
Cost of Fuels	0.000004589	0.000004819	0.000004823	0.000004450	0.000004654	0.000004657	0.000004802	0.000004989	0.000004992
	(0.000002517)	(0.000002514)	(0.000002520)	(0.000002697)	(0.000002701)	(0.000002708)	(0.000002842)	(0.000002846)	(0.000002853)
Cost of Materials	0.000002670***	0.000002636***	0.000002664***	0.000002975***	0.000002941***	0.000002970***	0.000002975***	0.000002942***	0.000002970***
	(3.987e-07)	(3.920e-07)	(3.933e-07)	(4.068e-07)	(4.011e-07)	(4.025e-07)	(4.154e-07)	(4.090e-07)	(4.114e-07)
Cost Pur. Electricity	0.000003859	0.000003913	0.000003890	0.000003567	0.000003623	0.000003593	0.000004769	0.000004831	0.000004795
	(0.000002882)	(0.000002835)	(0.000002829)	(0.000003042)	(0.000003000)	(0.000002995)	(0.000003284)	(0.000003251)	(0.000003247)
Ln(Income)	0.02047	0.006604	0.009297	0.01170	0.0002351	0.002565	-0.01525	-0.02662	-0.02475
	(0.06037)	(0.06415)	(0.06259)	(0.05775)	(0.06089)	(0.05962)	(0.05280)	(0.05535)	(0.05446)
Population	-2.995e-08	-3.488e-08	-2.591e-08	-7.257e-08	-7.660e-08	-6.874e-08	-4.849e-08	-5.173e-08	-4.533e-08
	(1.520e-07)	(1.523e-07)	(1.527e-07)	(1.341e-07)	(1.338e-07)	(1.341e-07)	(1.648e-07)	(1.653e-07)	(1.647e-07)
Unemployment Rate	-0.002929	-0.002808	-0.003291	-0.002266	-0.002080	-0.002555	-0.008748	-0.008605	-0.009059
	(0.008321)	(0.008227)	(0.008180)	(0.008652)	(0.008559)	(0.008513)	(0.008371)	(0.008247)	(0.008218)
P&P Share of GDP	0.09434*	0.09744**	0.09892**	0.09469*	0.09781*	0.09912**	0.1042**	0.1066**	0.1077**
	(0.03789)	(0.03695)	(0.03658)	(0.03864)	(0.03800)	(0.03757)	(0.03892)	(0.03870)	(0.03822)
Paper Consumption	-0.00008277*	-0.00008518*	-0.00008480*	-0.00008138	-0.00008360*	-0.00008320*	-0.00008300	-0.00008504	-0.00008464
	(0.00004150)	(0.00004132)	(0.00004119)	(0.00004180)	(0.00004167)	(0.00004156)	(0.00004557)	(0.00004546)	(0.00004533)
Recovery Rate	0.01633	0.01907	0.01872	0.01557	0.01803	0.01771	0.01714	0.01936	0.01908
	(0.01778)	(0.01792)	(0.01787)	(0.01741)	(0.01757)	(0.01753)	(0.01910)	(0.01926)	(0.01921)
BMP	-0.01644	-0.01340	-0.01312	-0.01614	-0.01352	-0.01325	0.01172	0.01421	0.01445
	(0.03141)	(0.03191)	(0.03164)	(0.03463)	(0.03520)	(0.03499)	(0.03654)	(0.03727)	(0.03713)
Stumpage	-0.005907	-0.006165	-0.006526	-0.005974	-0.006268	-0.006550	-0.005176	-0.005480	-0.005665
	(0.004854)	(0.004856)	(0.004893)	(0.005028)	(0.005047)	(0.005068)	(0.004947)	(0.004999)	(0.004980)
Adjusted R^2	0.4363	0.4390	0.4417	0.3986	0.4000	0.4023	0.3850	0.3862	0.3881
Observation†	3900	3900	3900	3900	3900	3900	3900	3900	3900

All regressions include state and year dummies and a constant - Standard errors in parentheses

†Rounded to nearest hundredth - *p<0.05 **p<0.01 ***p<0.001

Table 2.8. Robust Fixed Effect Estimation with Controls - Northeast Region

	Total Employment			Production Workers			Production Hours		
MACT98	-0.3143*		-0.1853	-0.2897*		-0.1897	-0.3135		-0.1742
	(0.1392)		(0.1072)	(0.1395)		(0.1064)	(0.1568)		(0.1157)
BAT98	-0.04835		0.02471	-0.06586		0.02324	0.01817		0.03577
	(0.08619)		(0.07818)	(0.08445)		(0.07319)	(0.09583)		(0.07368)
MACT01		-0.3600*	-0.2174*		-0.3059*	-0.1600		-0.3855*	-0.2509*
		(0.1326)	(0.07966)		(0.1401)	(0.08965)		(0.1625)	(0.1056)
BAT01		-0.06212	-0.07859		-0.1011	-0.1162		0.04568	0.01963
		(0.08552)	(0.07667)		(0.09080)	(0.07742)		(0.1143)	(0.1048)
Cost of Fuels	-6.109e-07	4.495e-09	-1.393e-07	-0.000001453	-8.645e-07	-0.000001015	-4.967e-07	-7.520e-09	-1.237e-07
	(0.000003041)	(0.000003103)	(0.000003139)	(0.000002898)	(0.000002976)	(0.000003018)	(0.000003488)	(0.000003557)	(0.000003589)
Cost of Materials	0.000003823***	0.000003755***	0.000003797***	0.000004177***	0.000004108***	0.000004151***	0.000004005***	0.000003954***	0.000003987***
	(9.662e-07)	(9.079e-07)	(9.324e-07)	(9.971e-07)	(9.406e-07)	(9.668e-07)	(9.877e-07)	(9.413e-07)	(9.689e-07)
Cost Pur. Electricity	-0.000003523	-0.000003159	-0.000003058	-0.000004449	-0.000004078	-0.000003973	-0.000005409*	-0.000005212	-0.000005126
	(0.000002596)	(0.000002631)	(0.000002591)	(0.000002436)	(0.000002407)	(0.000002333)	(0.000002516)	(0.000002557)	(0.000002496)
Ln(Income)	0.2666	0.2644	0.1940	0.4678	0.4796	0.4070	0.2507	0.2435	0.1808
	(0.4169)	(0.3797)	(0.4073)	(0.3864)	(0.3480)	(0.3755)	(0.4230)	(0.3819)	(0.4164)
Population	0.000001322	0.000001670	0.000001919	-6.020e-07	-3.152e-07	-5.639e-08	-0.000001934	-0.000001658	-0.000001446
	(0.000003059)	(0.000002913)	(0.000002954)	(0.000002357)	(0.000002215)	(0.000002269)	(0.000002015)	(0.000001896)	(0.000001942)
Unemployment Rate	0.02291	0.02365	0.02654	-0.005644	-0.005749	-0.002798	-0.001106	0.000003559	0.002746
	(0.02508)	(0.02473)	(0.02453)	(0.02648)	(0.02702)	(0.02611)	(0.02497)	(0.02593)	(0.02502)
P&P Share of GDP	0.1676**	0.1703***	0.1698***	0.1606**	0.1629**	0.1624**	0.1757**	0.1783***	0.1779***
	(0.04804)	(0.04472)	(0.04405)	(0.04823)	(0.04539)	(0.04468)	(0.04954)	(0.04710)	(0.04652)
Paper Consumption	0.00002755	0.00002597	0.00003154	-0.00002699	-0.00002988	-0.00002416	-0.000008827	-0.000009155	-0.000004006
	(0.00005754)	(0.00005627)	(0.00005734)	(0.00006069)	(0.00006263)	(0.00006131)	(0.00005633)	(0.00005787)	(0.00005655)
Recovery Rate	-0.03236	-0.03087	-0.02922	-0.01843	-0.01721	-0.01549	-0.01611	-0.01505	-0.01365
	(0.02888)	(0.02707)	(0.02824)	(0.03257)	(0.03111)	(0.03224)	(0.03101)	(0.02977)	(0.03095)
BMP	-0.1268	-0.1199	-0.1331	-0.1097	-0.1008	-0.1145	-0.05269	-0.04789	-0.05961
	(0.07302)	(0.07881)	(0.07792)	(0.08063)	(0.08555)	(0.08413)	(0.08849)	(0.09242)	(0.09227)
Stumpage	-0.8095	-0.8108	-0.8631	-0.1418	-0.1300	-0.1836	-0.1481	-0.1569	-0.2054
	(0.7308)	(0.7071)	(0.7194)	(0.6511)	(0.6578)	(0.6485)	(0.6240)	(0.6179)	(0.6188)
Adjusted R^2	0.6207	0.6282	0.6317	0.5935	0.5989	0.6026	0.5609	0.5647	0.5666
Observations†	700	700	700	700	700	700	700	700	700

All regressions include state and year dummies and a constant - Standard errors in parentheses

†Rounded to nearest hundredth - *p<0.05 **p<0.01 ***p<0.001

Models reported in Tables 2.7 and 2.8 are similar to the ones discussed previously, but do include plant fixed effects. In these cases, variations from plant-specific variables such as air, water, old, pulp and kraft are implicitly captured by the fixed effect estimator and, thus, dropped from the output. At the national level, now only BAT-covered plants seem relevant and the effects were consistently higher immediately after promulgation date compared to compliance years. Specifically, the impact is of 24% lower employment after 1997 and close to 19% lower employment after 2000. Both production workers and production hours had declines of over 21% after 1997 and over 16% after 2000. When all years are combined, BAT-covered plants seems to have experienced an overall decrease of close to 16% in employment and production workers and 15% in production hours. Interestingly, only MACT-covered mills were affected in the Northeast with 1998, 2000 and overall effects in the order of 31%, 36% and 21% declines in total employment, close to 29%, 30% and 0% declines in production workers, and roughly 31%, 38% and 25% lower levels of production hours, respectively.

As far as the control variables included in the last specifications for the national sample, only cost of material is statistically relevant but its magnitude remains insignificant. The same is true in the Northeastern models. Nationally, no statistically significant effects are obtained from Ln(Income), population, unemployment rate, paper recovery rate, BMPs and stumpage prices. The direction and magnitude of the P&P Share of GDP and Paper Consumption variables remain remarkably similar to those reported in Table 2.5. The Northeastern models only return statistically significant results for P&P Share of GDP and its impact is around 17% higher employment and production hours, and just over a 16% increase in production workers.

These findings stem from models which are inherently imperfect and thus results should be examined with caution. The main limitations of this work are threats to identification resulting from potential selection bias and omitted variables. The assignment of plants to treatment and control groups is not entirely random and the systematic differences between these groups may obscure some of the statistical analysis. However, the Air and Water dummy variables should theoretically neutralize any confounding effects that these systematic differences may introduce. Additionally, using similar data and models, Gray et al. (2014) performed robustness checks which confirmed the validity of a difference-in-differences (DiD) estimator in these models. On the other hand, the omitted variables issue is largely related to lack of data on plants' capital-labor (k/l) ratios. As facilities become more efficient and technological advances increase the productivity of machinery, labor demand is likely to suffer as mills will move towards reliance on the more efficient capital over human labor. This, in fact, may be a large explanatory factor behind the latest declines in employment at mills, especially since the manufacturing processes at mills become more sophisticated. Porter and van der Linde's theory would even suggest that the Cluster Rule may help exacerbate this trend towards efficiency. Unfortunately, none of the models in this analysis include data on capital-labor ratios which implies that some of the effects reported could have been overestimated. This is especially true in the baseline and robust models, but the plant-specific fixed effects should serve as controls for k/l variations at the plant level. Lastly, future research should conduct a Wald test on the null hypothesis that the addition of $MACT * CRYear$ and $BAT * CRYear$ equals 0. Since the complete differential effect of the Cluster Rule on BAT mills relative to the control group can be obtained from the cumulative effect of these two coefficients, rejecting the null hypothesis of such Wald test would provide further evidence of an effect of the Cluster Rule on employment at mills.

2.5 Conclusions

The pulp and paper industry has undergone substantial structural changes in the last few decades. Various factors play important roles in shaping the nature of the industry and, due to its highly pollution-intensive nature, environmental regulations have been part of these factors. A rather recent and large decline in employment at pulp and paper plants nationally, and especially in regions such as the Northeast, motivates studies of this nature to identify major drivers of labor demand in the industry. Using confidential establishment-level data from the Annual Survey of Manufacturers and the Census of Manufacturers, collected at a Census Bureau's Federal Statistical Research Data Center in Boston, MA, and employing a difference-in-differences (DiD) estimator, I found evidence of negative employment effects from the so-called Cluster Rule on employment levels at pulp and paper mills both at the national level and in the Northeastern region of the United States.

At the national level, evidence of negative impacts on employment levels in this industry are strong. Specifically, these results suggest that mills which were subject to compliance with BAT standards for water discharges at the time of the rule promulgation have suffered roughly a 20% decline in employment. The magnitude of this effect is larger for Northeastern mills -above 30% on average- and the impact stems from MACT standards instead, both at the time of promulgation and the effective compliance date. However, this finding is only observed in specific models and statistically significant at only a 95% confidence level. All results are relatively consistent over different measures of employment such as production workers and production hours. My research expands the work of Gray et al. (2014) and these impacts are considerably higher than those reported in their study and discussed in the literature review.

These conclusions have policy relevance. The closure of mills has impacted many small communities which relied on them for taxes and for maintaining an economically sustainable population. Efforts to design regulations which focus on costs and potential effects on labor and productivity, so as to avoid some of the impacts found in this work, are of critical importance, especially in regions where entire communities can be affected. Furthermore, understanding what types of plants or processes tend to be related to higher levels of employment is crucial when considering new developments in the pulp and paper industry. Further research should include data on capital-labor (k/l) ratios to understand potential effects of improvements in technology and productivity on labor demand. This analysis could further benefit from robustness checks related to the validity of DiD estimators and plant-specific information on emissions.

CHAPTER 3
WOOD-BASED BIOFUEL REFINERIES DEVELOPMENTS IN MAINE

3.1 Introduction

Maine is the most heavily forested state in the U.S. and has long been known for its iconic, mostly naturally regenerating forests. The state's forest products industry is among the most diverse in the nation (MFS, 2018). However, Maine's forest resource faces increasing pressure from shifts in ownership, declining markets, disturbance agents (e.g., "pests," spruce budworm, emerald ash borer) and climate change. From ecological, economic, and social perspectives, there is a growing interest in determining the value of emerging markets and opportunities for Maine's forest product industry as well as identifying cost-effective policies to achieve its market potential. Simultaneously, the pulp and paper industry in Maine has suffered an accelerated decline during the last two decades. The closing of pulp and paper mills has spurred a growing interest in re-purposing idle facilities in order to restore economic activity and bring back growth to the many rural towns where these plants used to operate. Recent research has highlighted the potential for emerging technologies such as wood-based cellulosic biofuels to enhance the state's forest product industry (Rubin et al., 2015). However, uncertainty about the economic viability and ecological integrity of renewable fuels has raised concerns about the long-term viability of investing in bio-refineries in the state.

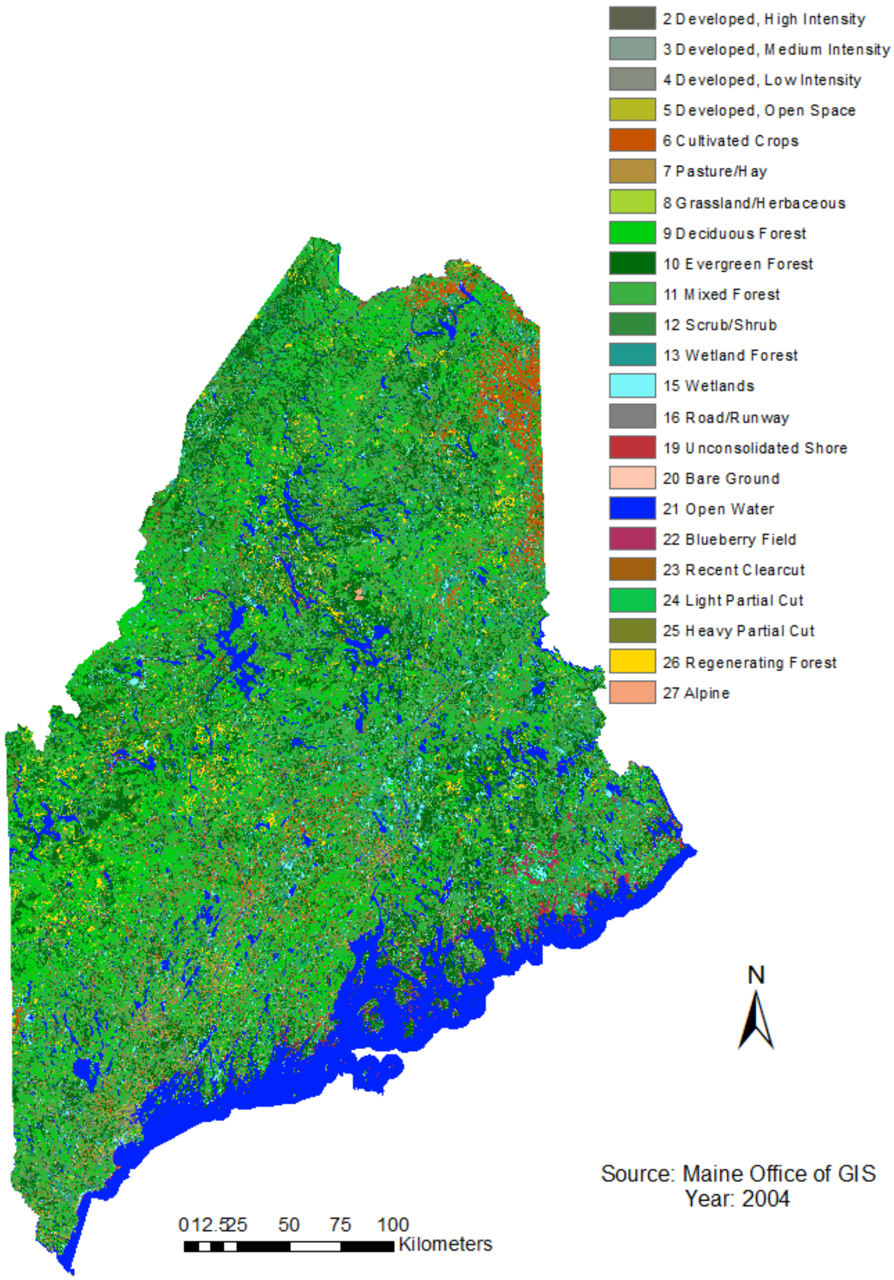
In this chapter, I provide a thorough review of the literature on the socioeconomic feasibility of biofuel refineries developments in Maine. Previous studies address this question from various perspectives, such as social acceptability and public awareness of biofuels (Noblet et al., 2012; Silver et al., 2015), biomass availability in Maine (Wharton and Griffith, 1998; Laustsen, 2008; Rubin et al., 2015), biomass potential in the next decades and forest carbon implications (Smeets and Faaij, 2007; Daineault et al., 2012; Lauri et al., 2014; Sohngen and Tian, 2016), costs of delivered biomass in Maine (Whalley et al., 2017), life cycle assessments (Neupane, 2015) and techno-economic analyses of biofuel production (Langton, 2016; Gunukula et al., 2018), and even market potentials for by-products from biorefineries (Dalvand et al., 2018).

The decision to pursue the development of a wood-based biofuel refinery in Maine is multi-faceted and various factors inform it. There is an ongoing effort at The University of Maine to combine most of the research conducted up to date and create a Multi-Criteria Decision Analysis (MCDA) tool to summarize and simplify these various factors and their outcomes. Nevertheless, multiple researches conclude that biofuel developments are economically feasible and should be considered as an alternative to pulp and paper mills to bring back economic activity and prosperity to small Maine communities which heavily rely on the forest products sector.

3.1.1 Maine's Forests

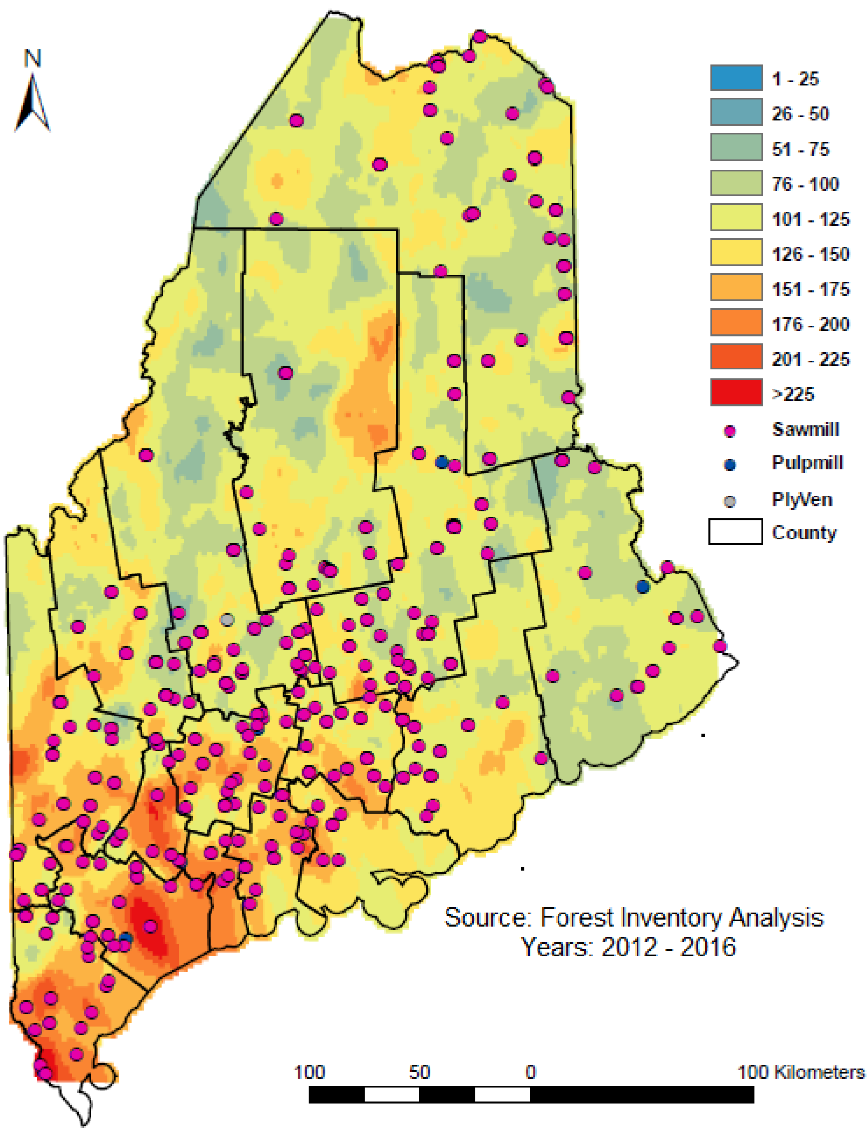
The predominant land cover type in Maine is forest lands. According to the Maine Forest Service (MFS), 90% of Maine's land is forested, which makes Maine the most heavily forested state in the nation. Ninety five percent of all forested areas are privately owned, largely by private companies and family owners. Approximately, 39% of Maine's forests contain softwood species, mostly located in Northern portions of the state, and 61% contain hardwoods, widely spread across Southern regions. The most common species in Maine are aspen, oaks, birch, spruces, red and sugar maples, white and red pine, among others. According to the latest Silvicultural Activities Report from MFS, only 344,210 acres were harvested in Maine in 2016. This is the lowest amount of harvesting in decades since the annual total area of harvest since 2000 has consistently been above 500,000 acres. Figure 3.1 is a map of land cover types in Maine obtained from the Maine Office of GIS.

Figure 3.1. Land Cover - Maine, USA



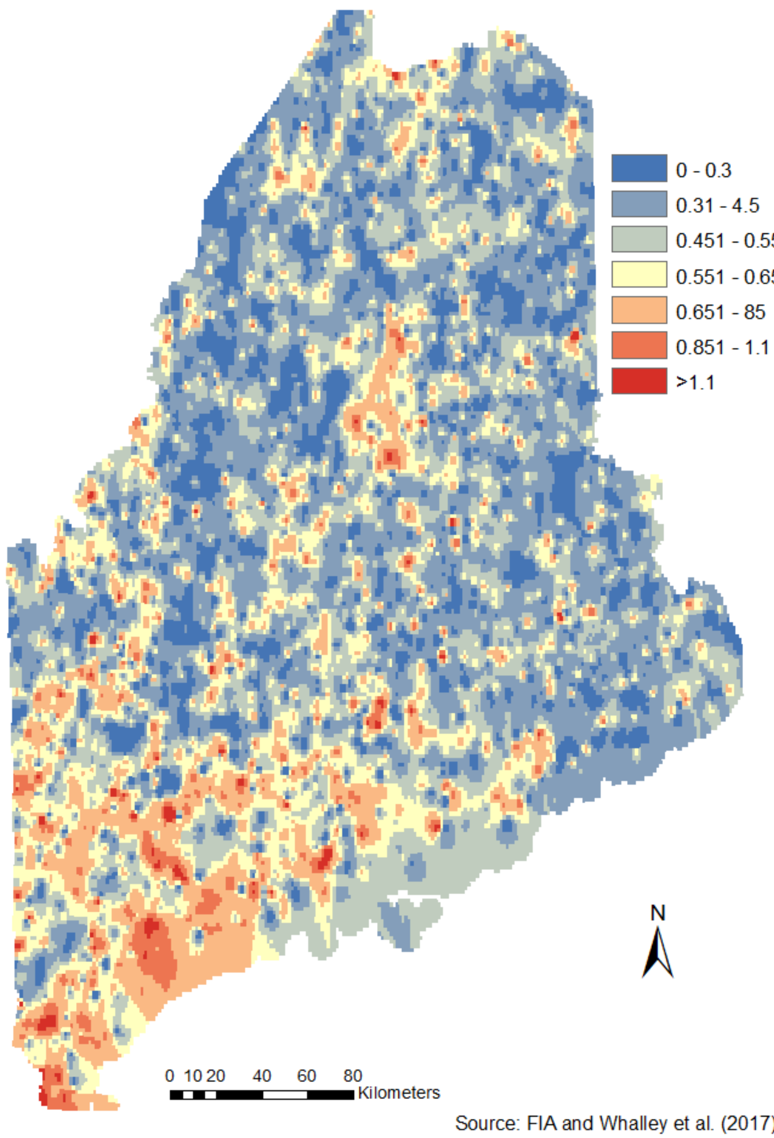
The frequent shades of green in the map represent different types of forests, and are only marginally interrupted by water bodies, agricultural lands in the Northeastern region of the state, and urban developments. The state's abundance of forestland can also be represented by available stock of woody biomass and Figure 3.2 plays that role. This map also shows the geographic distribution of wood manufacturing mills in the state.

Figure 3.2. Above Ground Biomass Stock (dry t/ha)



This figure shows the geographic distribution of above ground woody biomass stock in dry tonnes (DT) per hectare. These data were collected from the Forest Inventory Analysis and are based on plot estimates from 2012 to 2016. The highest density of biomass per hectare occurs in the Southern areas of the state, with moderate to high levels only sporadically in central and upper regions. On average, a hectare in Maine contains roughly 120 DT of biomass, and the most dense areas can comprise up to over 700 DT. The stock of biomass can be further converted into sustainable biomass, following some of the methods by Rubin et al. (2015) and Whalley et al. (2017) discussed below. On this line, Figure 3.3 is a map of above ground sustainable woody biomass stock in DT per hectare.

Figure 3.3. Above Ground Sustainable Biomass Stock (dry t/ha)



3.1.2 Wood-Based Biofuel Refineries

The Forest Bioproducts Research Institute (FBRI) at the University of Maine has developed a process called Acid Hydrolysis Dehydration (AHDH) which converts wood-based biomass into Thermal Deoxygenated (TDO) oil which can be upgraded to a drop-in[1] biofuel (Langton, 2016). This process can be ecologically sustainable when the biomass is obtained from residues resulting from other forest silvicultural activities. This invention, coupled with the recent decline in the pulp and paper industry, has brought attention to the wood-based biofuel refineries as the next step for the forest products industry in Maine. On this note, several studies have investigated the social, economic and technical feasibility of wood-based biofuel developments in the state of Maine.

Initially, research has focused on the social acceptability of wood-based biofuel production in the state of Maine. Noblet et al., (2012) conducted a survey and various focus groups in parts of Maine and New England and concluded that people make their fuel choice primarily based on price. They also found that there is a lack of awareness of ethanol sources, but those who recognize its presence on their fuel tend to drive, on average, 60 miles more per week than other groups. Their research suggest that consumers in the Northeast would value biofuels greatly from economic (competitive prices, job creation, etc.), national security (less dependence on foreign oil) and environmental (improvements in air-quality) perspectives. Beyond consumers, Silver et al., (2015) investigated the perceptions about this industry from private landowners, who own most the forestlands of Maine and would become vital stakeholders in the supply of woody biomass. They interviewed 32 private woodland owners (PWOs) and found that only 28% of them had harvested specifically for bioenergy purposes in the past 10 years. They concluded that anthropocentric values prevailed over biocentric values and overall knowledge of biomass and

[1] "Drop-in" refers to fuels compatible with current infrastructure.

bioenergy was poor. On this line, Joshi et al., (2013) conducted a choice experiment using a nested logit model to understand the harvesting preferences of nonindustrial private forest (NIPF) landowners in the Southern United States. Their data were obtained from a survey administered to 2560 NIPF landowners in the state of Mississippi from December 2009 to February 2010. Their results suggest that age of the landowner plays a detrimental role in the propensity to harvest for woody-biomass, while higher education and income were favorable factors. They concluded that, overall, most NIPF landowners are not averse to supplying woody biomass for wood-based bioenergy and that higher awareness on ecological factors would increase willingness to participate in the wood-based biofuel industry.

On the biomass availability questions, several studies have focused on Maine and one of the latest estimates, by Rubin et al. (2015), calculated sustainable biomass obtainable taking into account retention rates for ecosystem health and forest regeneration. Wharton and Griffith (1998) challenged traditional volume measures of biomass and created estimates from regressions. Their result was that, in 1995, Maine had 900 million dry tons of biomass on timberland and nearly 928 million dry tons of biomass on all forest land. Laustsen (2008) calculated biomass available for existing pulp and paper mills in the state and found that Maine could provide up to 1.9 million DT per mill. Taking into account 60-mile woodshed areas (including out-of-state regions), he concluded that each mill could be supplied with up to 3 million DT annually. Rubin et al. (2015) conducted the first of these studies considering the need for retention rates and focusing on nonmerchantable residue from harvest operations. Their model uses Forest Inventory Analysis (FIA) data on nonmerchantable limbs and tops, cull trees[2] and saplings[3]. Their estimates are focused on consistency with EPA regulations on what is considered renewable

[2]Their study considered cull trees which are 5 inches in diameter breast height (DBH) or larger and nonmerchantable because of rot or roughness.

[3]Saplings are trees with 1-4.9 inches of DBH.

biomass for the assessment of biomass available for cellulosic drop-in (TDO) biofuels. Their main conclusion is that Maine can sustain up to 3.9 million DT of sustainably harvested biomass annually. Based on these estimates and their claim that a new, commercial-scale biofuel refinery would require 2,600 m^3 of biomass per day to operate, preliminary work from the University of Maine, following the approach of Daigneault et al. (2012), estimates that under current biomass demand scenarios, Maine could sustain up to 11 new plants. A high biomass demand scenario, driven by local, national and international factors, could even sustain up to 16 biorefineries, since high demand for biomass has the potential to increase prices and foster higher forest management practices. On a less localized level, the "Billion-Ton Report" is a vast effort from the Energy Department to assess the potential availability of biomass in the United States with economic and sustainability considerations. The major conclusion of the latest report is that the United States is capable of sustainably supplying at least one billion dry tons of biomass from various sources with the potential to be used for energy generation without affecting agricultural production (Billion-Ton Report, 2016).

An important aspect to be considered to assess the viability of wood-based biofuel refineries in the state of Maine is the environmental impact. Neupane (2015) created an integrated life cycle model through a multi-criteria decision analysis to address this question. Comparing this potential source of new energy with conventional fossil fuel sources, he concluded that TDO biofuels would produce substantially low greenhouse gas emissions. A major component in reaching this conclusion is the treatment of some of the major production by-products, such as furfural and char. Neupane's goes on to develop models and produce results in line with the studies discussed below.

Beyond the availability of biomass for potential TDO biofuel refineries, other studies have investigated the feasibility of new biofuel developments in Maine from various economic perspectives. Whalley et al. (2017) developed a comprehensive supply chain model to calculate the delivered cost of biomass chips to a refinery for biofuel production under different scenarios. Their study included stumpage prices, costs of harvesting and chipping, and costs of transportation. They found that if harvesting was excluded and only forest residues were procured, the delivered biomass cost ranged from $4 to $24 per green tonne (GT). If a portion of the harvesting costs was included, these estimates intuitively increased to $8 to $82 per GT. Their results were highly sensitive to variations in diesel prices, since diesel is a key input in both the harvesting and delivery process. Dalvand et al. (2018) investigated the potential market for furfural, which is a highly valuable by-product of the TDO process of fuel production. They found a significant market for furfural derivatives which not only aids in making biofuel production profitable by cross-subsidizing the process but can also highly impact and even generate their own markets. These findings create the possibility of developing biorefineries focused on different product suites, which has been studied and is discussed below.

Two studies have conducted techno-economic analyses of the TDO process for production of biofuels from Maine's harvest residues. Langton (2016) expands Whalley et al. (2016) costs estimates by following the process through the production stage under various comprehensive scenarios. Langton's cost estimates resulted in $0.79 to $2.25 per gallon total production costs after taxes in Maine. He claims these cost values would generate $49.5 to $55.4 million annually in excess profits. His cost and profit estimates are based on scenarios which vary the utilization and cost of by-products such as furfural and char, and the assumptions underlying models of delivered costs of biomass. Gunukula et al. (2018) examined the economic impact of TDO biorefineries under two different product suites scenarios and considering plant siting in greenfields or brownfields. Their product variations include production and commercialization of fuel and furfural or production and commercialization of fuel and levulinic acid. As far as siting, brownfields refer to the re-purposing of well-maintained but currently idle pulp and paper mills. They conclude that production of fuel and furfural would turn into a product-driven biorefinery, while the levulinic acid suite would be driven by energy production. Their total capital investments for a TDO oil and furfural plant is estimated at roughly $451 million and the respective annual operating costs at $81 million. These numbers differ for a Levulinic acid plant, since capital investments estimates are $470 million and annual operating costs rise to $83 million. Regardless of product suite choice this study concludes that capital investments can be reduced by 23% to 27% by building TDO refineries in well-maintained, re-purposed pulp mills.

Lastly, Crandall et al. (2017) estimated the economic impact of a potential biorefinery built in Maine. Their analysis modelled a typical plant that would employ 40 workers and consume 2,000 dry metric tonnes of biomass daily. Their analysis is conducted on IMPLAN (Impact Analysis for Planning), which is a software originally developed by the U.S. Forest Service and that uses Input-Output models to calculate direct and indirect effects of economic activity through multipliers. Based on Langton (2016)'s estimates of $550 million in construction costs, their IMPLAN model found that a new biorefinery would generate a direct contribution of close to $69 million, 40 new jobs and $2,600,000 in compensations. When adding the induced effects in the forest product industry and the entire state economy, the new plant's total impact increases to over $88 million in output, 160 jobs and $7,674,356 in compensations.

None of the previous studies which aimed to assess the feasibility of wood-based biorefineries developments in Maine has examined the procurement competition in overlapping woodshed areas between the potential new developments and other currently operating forest products manufacturing industries (e.g., sawmills, pulpmills, etc.). Anderson et al. (2011) conducted a geographic information system-based spatial analysis of wood procurement for sawmills in Maine, New Hampshire, Vermont and parts of New York state. They used data from 273 survey responses to create woodshed maps and estimate woodshed areas of nonrespondent mills. They found that most sawmills in the Northeastern United States procure the majority of their wood from within 30 to 70 miles from the mill locations. Specifically, they report that the average woodshed area for sawmills in Northern New England is 4,230 mi^2, which is roughly equivalent to a 37-mile radius.

Future research on this area should use Anderson et al. (2011)'s estimates and create a geographic information system-based spatial analysis of wood procurement on a fully operating forest products industry in Maine. As an alternative to their estimates, a survey of sawmills in Maine could be conducted to gain knowledge on typical sawmills' procurement practices in the state. Additionally, data on pulp and paper mills capacity can be used to model woodshed areas based on their demand for biomass. Above ground biomass stock data can be obtained from Forest Inventory Analysis data, as in Figure 3.2. Following the approach from Rubin et al. (2015) and Whalley et al. (2017), the stock of above ground biomass can be converted into a "sustainable" biomass estimate, provided by nonmerchantable harvest residues and observing retention rates. Finally, potential woodshed areas for new biorefineries can be calculated based on their predicted intake of biomass. These data could be combined with road networks and conserved lands information to confirm the accessibility of biomass. Spatial, Geostatistical and Network Analyst tools from ArcGIS 10.5 could be used to model spatial competition for woody biomass and identify optimal locations for new developments in the forest product industry.

3.2 Conclusions

Given the ongoing structural changes in the entire pulp and paper industry, which deeply affect the entire forest products industry and, specifically, many small communities in places like Maine, the need to assess potential alternatives and new markets for forest products is imperative. One of the most prominent alternatives in the state of Maine is the development of wood-based biofuel refineries. This chapter provided a review of some of the most relevant literature for the state of Maine on this topic. It also provided suggestions for future further research.

All of the studies presented in this chapter concluded, from their own perspectives, that developments of wood-based biofuel refineries are feasible and should be considered as an alternative or complement to existing forest products manufacturing industries. The impact these developments could have on small communities are enormous and would help to revert the current negative economic and population outlooks which, in some cases, threaten towns' very existence. In pursuing such developments, several factors can play substantial roles in determining their overall impact and should therefore be carefully considered. Some of these factors include diesel prices, which deeply affect mills' cost of delivered biomass, production and commercialization of by-products such as furfural and char, which have impacts on a plant's initial capital investment costs, annual operating costs and long-term profitability, and developing on re-purposed idle pulp and paper mills facilities or plain "greenfields," which also significantly impacts initial capital investment estimates.

Maine's forests remain a large part of the state economy and play a very important role in Mainer's lives, sustaining massive industries, attracting tourism and providing superb outlets for recreational activities. The forest products industry has continually evolved and continues to do so today, and the role of the pulp and paper industry continues to be central for the sector. The hope is that this work contributes to the conversation as the future of this industry in Maine unfolds.

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APPENDIX

EMPLOYMENT CHANGE TRENDS IN SELECTED INDUSTRIES IN MAINE

Figure A.1. 12-Month Net Professional Business Industries' Employment Change in Maine

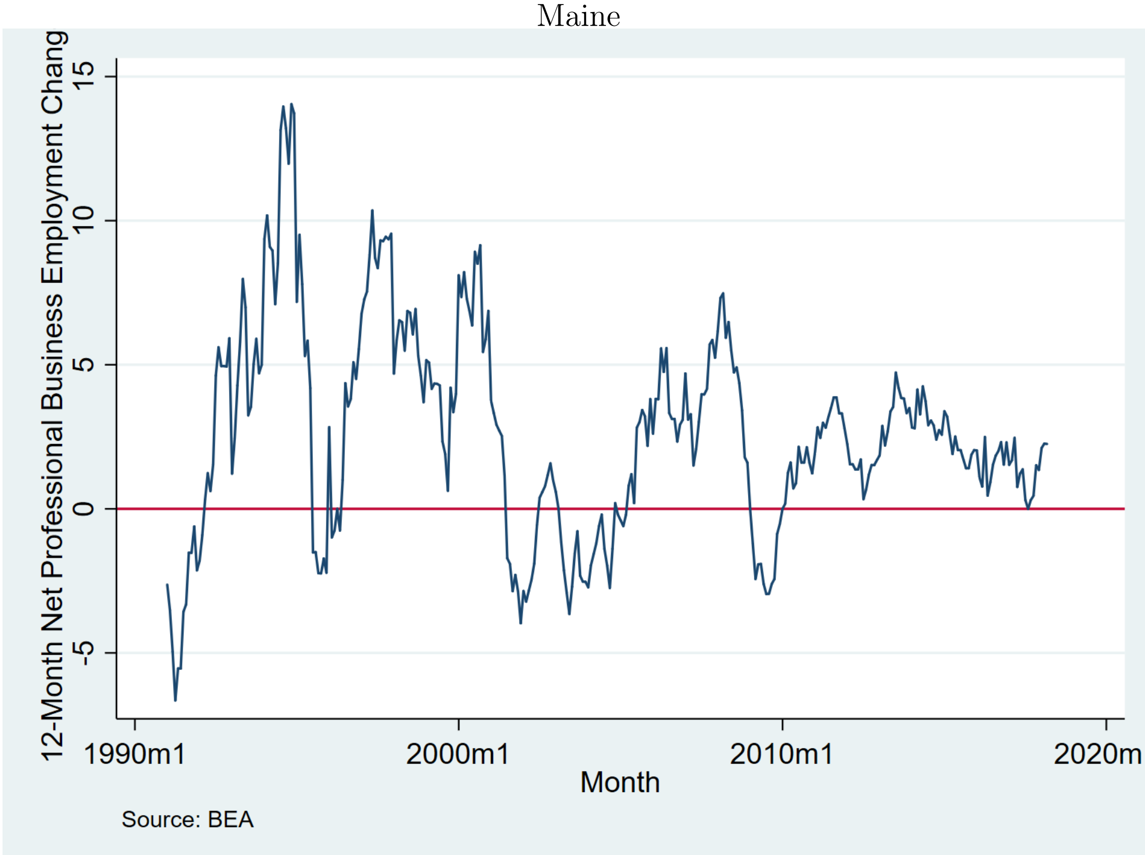


Figure A.2. 12-Month Net Hospitality Industry's Employment Change in Maine

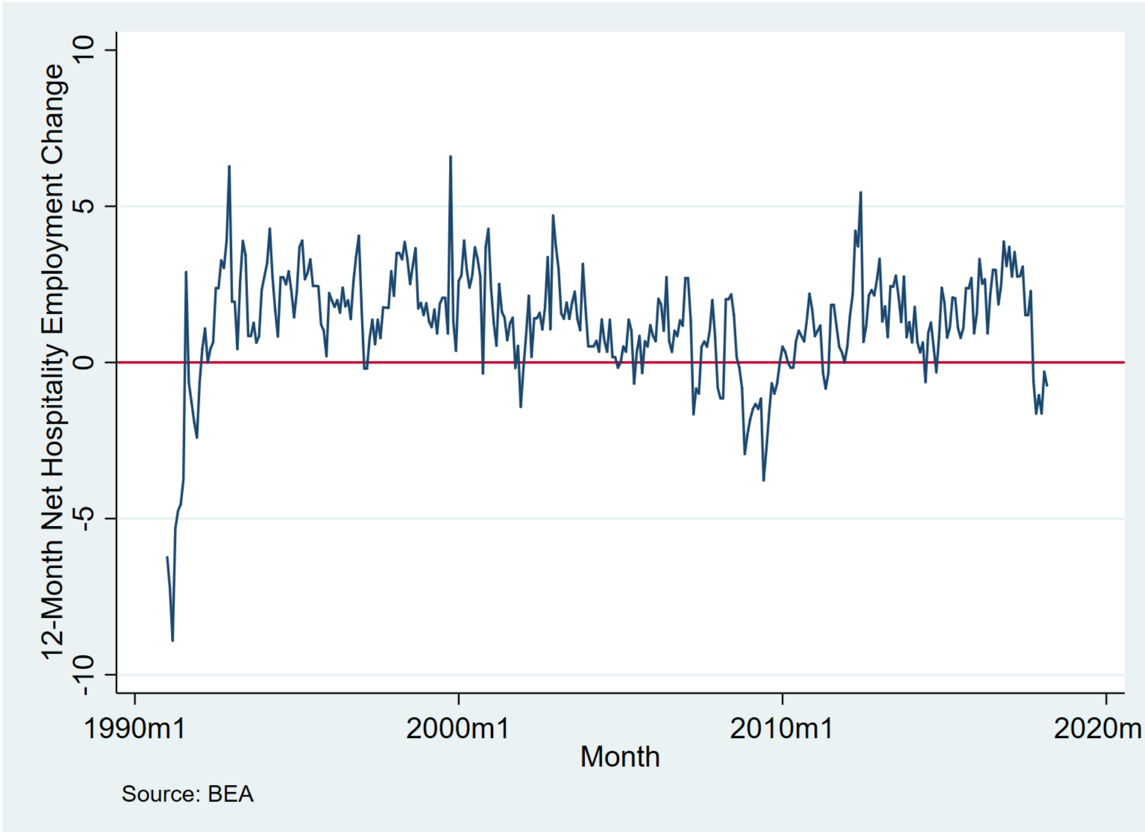
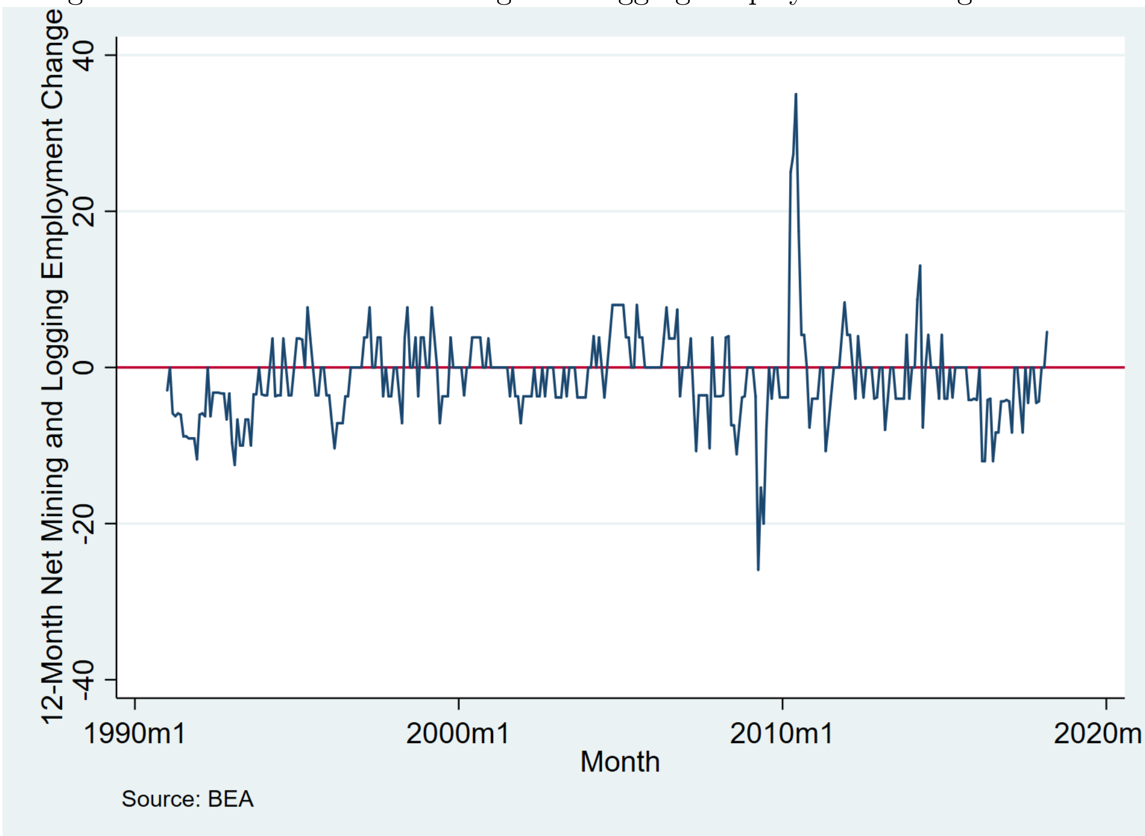


Figure A.3. 12-Month Net Mining and Logging Employment Change in Maine



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Ariel Listo was born in Buenos Aires, Argentina in 1994. He obtained his Bachelor of Arts in Economics (magna cum laude), with minors in Mathematics and International Relations from St. Thomas University, Florida in May 2016. He enrolled in the School of Economics at the University of Maine in August 2016 where he worked as a Research Assistant with Dr. Adam Daigneault, Assistant Professor of Forest, Conservation, and Recreation Policy in the School of Forest Resources. Ariel was also a Teaching Assistant for Principles of Microeconomics and Resources Economics & Policy courses in Fall 2016.

He has been working under the Sustainable Energy Pathways project from the National Science Foundation where his role was to assess economically feasible ways to re-purpose paper mill locations in Maine into renewable biofuel refineries. Ariel has presented his research findings at the 2017 European Biomass Conference and Exhibition in Stockholm, Sweden. Ariel's research interests include resource and energy economics, macroeconomic policy, and the effect of environmental regulations on employment.

After receiving his degree, Ariel will be working at the Becker Friedman Institute at the University of Chicago as a Research Professional. He plans on pursuing a PhD in Economics after his work at Chicago. He is a candidate for the Master of Science degree in Economics from the University of Maine in August 2018.