AN ABSTRACT OF THE DISSERTATION OF

Mindy S. Crandall for the degree of Doctor of Philosophy in Applied Economics presented on August 1, 2014.

Title: The Effects of Increased Supply and Emerging Technologies in the Forest Products Industry on Rural Communities in the Northwest U.S.

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Claire A. Montgomery

The development of a market for currently non-merchantable forest material, such as harvest residues of tops and limbs of trees or small diameter trees, has been suggested as a possible win-win solution that could: (i) provide a financial incentive to help motivate treatments to reduce wildfire risk or restore forest stands; (ii) provide a material that can be harvested and potentially processed in rural communities reeling from changes in the forest products industry and policy environment; and (iii) capture more value from timber management activities. There is potential for such a market to aid rural communities through the incorporation of intermediate processing centers, depots, as demand locations in a market model of the forest products industry. Intermediate processing centers would gather woody biomass (harvest residues only) for either local use or for refining and shipping to a hypothetical bio-refinery producing jet fuel. Modeling the supply of this traditionally non-merchantable material with spatially explicit potential locations for emerging technologies in biomass processing allows for a realistic analysis of the feasibility of such a market to stimulate rural development.

This dissertation models multiple scenarios for the utilization of harvest residues within the current forest products market in western Oregon. Scenarios considered include ones incorporating different establishment and operating costs of the depots and functions of the intermediate processing centers (dependent and independent depots) to model potential options on the demand side. On the supply side, scenarios included incorporation of harvest residues with and without federal lands as sources of biomass material and the inclusion of this material under increases in federal harvest activities, designed to simulate management closer to that outlined in the Northwest Forest Plan. Results suggest that with the modeled exogenous market prices for residuals, there is limited potential for a biomass market for harvest residues to aid some of the hardest-hit rural communities in western Oregon, and there is little improvement in the potential for the market to aid these places under scenarios of increased federal harvest.

The Effects of Increased Supply and Emerging Technologies in the Forest Products Industry on Rural Communities in the Northwest U.S.

by

Mindy S. Crandall

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APPROVED:

Major Professor, representing Applied Economics

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Mindy S. Crandall, Author

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1. Introduction

1.1 Background and Motivation

The forest products industry has been a key component of the overall Pacific Northwest economy, and of the economies of many rural communities within the region, for the last century. The harvest of vast areas of old-growth stands and subsequent fast growing rotations of Douglas-fir and Ponderosa pine, from both private industry and federal forestlands, has allowed the region to dominate lumber and plywood production in the United States for many decades. However, the northwest forest products industry is vulnerable to macroeconomic cycles, particularly recessions and depressions, while changes in management, technology, and efficiency lead to mill closures and employment losses. Concerns over the effects of these trends on rural communities, along with a desire to develop a market for currently unmerchantible forest material, has led to great interest in the potential utilization of harvest residues or small trees as woody biomass inputs for heat, fuel, and power generation. This dissertation models the forest products industry in the presence of emerging markets in biomass utilization in order to ascertain what possible effects these developments may have on rural communities.

The tendency of the forestry products industry to “cut and run” from one region to another or experience wide swings in activity has led to concerns that forest-dependent community fates also rise and fall (Robbins 1985; Bunting 1997). The primary use of wood harvested in the northwest is for lumber or logs for export markets, resulting in demand that is closely tied to macroeconomic cycles in larger national or global economies (Cox 1974; Keegan et al. 2011). In the Northwest, increases in harvest on public lands during the post-World War II economic boom allowed high regional harvest levels to continue in the face of dwindling private stocks until the decline of old-growth forests and of species reliant on that habitat sharply curtailed federal harvest activity in the early 1990s. Figure 1 displays data from the Oregon Department of Forestry that charts this changing role of public and private harvests, along with fluctuations in the industry over the last century for Oregon (Andrews and Kutara 2005).

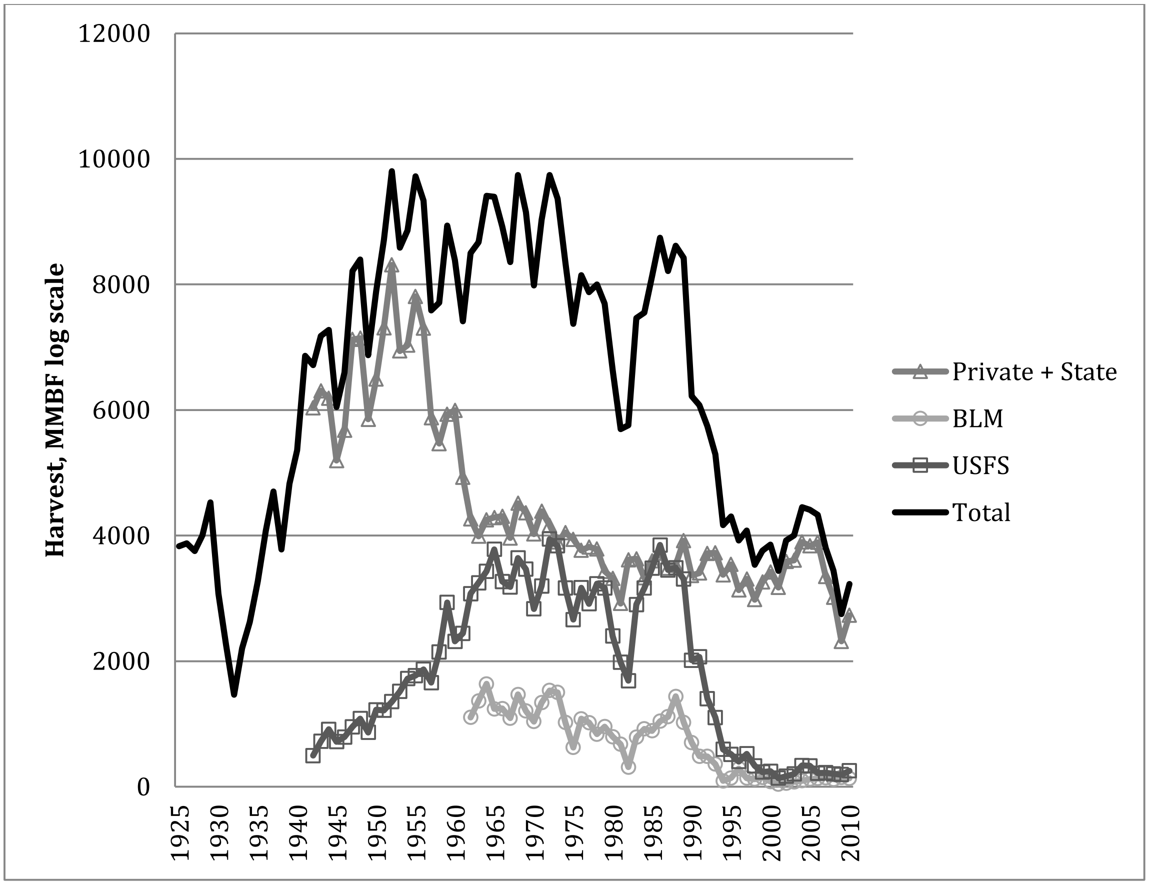

Figure 1. Harvest in Oregon, 1925-2009.

Private harvest dominated the total until the post-war boom of the 1950s, when public harvest began to garner an almost equal share. Private harvest has dominated the total again since the 1990s. Sharp declines in overall harvest have accompanied the Great

Depression, the recession in the early 1980s, the injunction against public harvest in 1991, and the recent Great Recession spurred by the collapse of the housing market in 2007.

Attempts to manage rural community outcomes and ease business cycle fluctuations of processing facilities (e.g. mills) through forest management practices was an explicit goal of sustained-yield harvest plans and other guiding principles of forest management in the mid-twentieth century (Robbins 1987; Hibbard 1999; J. J. Kennedy, Thomas, and Glueck 2001). In rural communities with strong ties to the industry, residents are buffeted by changes in employment and industry profitability resulting from these exogenous demand or supply shifts. It is the fates of these rural communities, and the forest products industry workers who reside or are employed there, that motivate this work.

Alongside these concerns over the interaction between the forest products industry and human communities has been increasing awareness of the decline in the ecological health and structure of western forests. On the Westside, concerns over changes in forest health have resulted from the landscape-level decline in old-forest structure (and concurrent decline of old-forest dependent wildlife species populations) and motivated ideas for management that can mimic older forest structure (Montgomery and Crandall 2014; Teensma et al. 1991; Montgomery, Latta, and Adams 2006). On the more fire-prone Eastside, changes in disturbance regimes due to suppression and exclusion of wildfire have led to significant departures in forest structure and composition (Agee 1996; Sugihara, Van Wagtendonk, and Fites-Kaufman 2006; Hessburg, Agee, and Franklin 2005). In the early twentieth century, fires were seen as deadly, destructive, and undesirable; the resulting focus on fire suppression has been increasingly challenged on scientific grounds, but proven remarkably slow to change (Donovan and Brown 2007; Egan 2009; Montgomery 2014). The effects of fire regime changes can also be seen from a human community standpoint as fires have become larger, more damaging of property, and more costly to fight when they do occur (Calkin et al. 2005; Safford, Schmidt, and Carlson 2009). There has been interest in the role of active management in restoring healthy forests and limiting the potential for human and community impacts of fire for both ecological and social reasons (Agee and Skinner 2005; Ager, Vaillant, and McMahan 2013; Stephens and Moghaddas 2005).

1.2 The Potential Role of Biomass

Although locally volatile, the forest products industry in the Northwest is a mature one that is likely to continue the production of sawlogs for lumber and export for the foreseeable future. Harvest of merchantable (sawlog-sized) forest trees in the Pacific Northwest is typically done with cable or ground-based logging systems. Once on the ground, trees are topped, delimbed, and bucked (sawn into log lengths) on site, either at the landing for cable systems or at the felling site for ground-based systems. This harvest residual of tops and limbs, along with some of the breakage and defect portions of the tree, is primarily waste material and presents a significant challenge for regeneration activities. Traditionally, piles of harvest residue or slash were burned; increasing social concern over smoke effects and risk of escaped fires has limited the degree of slash burning allowed.

Removal of unmerchantible or merchantable forest woody biomass can accelerate the development of old-growth characteristics, move current stands towards the more natural conditions old-growth has developed under, and reduce the severity and intensity of wildfires (Tappeiner et al. 1997; Poage and Tappeiner 2002; Zenner 2005; Carey, Lippke, and Sessions 1999). Locations where wildfire passed over areas that had previously been treated to reduce wildfire risks have proved that treatments decreased wildfire severity or intensity, changed fire progress, and reduced tree mortality (Finney, McHugh, and Grenfell 2005; Strom and Fule 2007; Raymond and Peterson 2005; Safford, Schmidt, and Carlson 2009). Restoration work could also bring jobs to rural communities in forested areas and offer a partial solution to the loss of woods work (Charnley 2006; Power 2006; Lorah and Southwick 2003). However, unmerchantible biomass removed to improve forest health and reduce wildfire risk is similar in quality to harvest residuals and has little current market value.

A market for the woody biomass currently left on site as harvest residues or the biomass that may be removed to reduce wildfire risk brings social, economic, and environmental benefits to forest and human communities. Ideally, the market would generate more stable jobs in rural areas, capture more value from forest stands, and facilitate ecological restoration. Woody biomass, unlike lumber, could be utilized locally or for end uses not connected to the volatile housing and export market. Demand for biomass can diversify the value resulting from forest management, leading to more stable economic conditions for rural communities and businesses. Finally, a market-driven demand for woody biomass can provide an incentive to removal of unmerchantible material from the forests and can take restoration or large-scale forest wildfire risk reduction from a cost borne by either the landowner or the taxpayers to a financially feasible option. Markets developed for this material can also facilitate restoration in

Westside forests, where the development of old-growth characteristics may be a priority. Proposed uses for woody biomass range from large-scale production of highly refined jet fuel or generation of electricity to community-level, small-scale projects such as wood-fired boilers or institutional heat and power production.

1.3 The Northwest Advanced Renewables Alliance (NARA) Project

This work was funded, in part, by the Northwest Advanced Renewables Alliance (NARA) project, a five year grant from the Agriculture and Food Research Initiative of the United States Department of Agriculture (USDA). The NARA project brings together 22 collaborators from educational groups and universities, private industry, and state organizations in order to: assess the feasibility of using woody biomass to create sustainable aviation biofuel in areas of the Pacific Northwest (Oregon, Washington, Idaho, and Montana); produce valuable co-products to aid in the economic viability of a bio-refinery; develop regional supply chains to initiate the industry; to increase rural development; and enhance bioenergy literacy for citizens and professionals (NARA 2013). The woody biomass considered includes both forest harvest residues and municipal solid wood waste.

Much of the focus of the NARA project is on developing the chemical pre-treatment, conversion, and fermentation process technologies capable of transforming cellulosic fiber into fuel on a very large scale, with the intent of producing 30 gallons of biojet fuel and assorted co-products from one bone dry ton of woody biomass at a dedicated bio-refinery requiring an estimated 770,000 bone dry tons (bdt) of woody biomass feedstock a year (NARA 2013). OSU’s part of the NARA project is assessing the viability of utilizing harvest residue material in as cost-effective manner as possible while ensuring the sustainability of the removal of biomass with respect to soil fertility and other nutrient cycling issues. This dissertation is situated within the first goal, assessing the economic feasibility of woody biomass as a feedstock in a new market for biofuel production while also considering the potential effects this utilization may have on specific communities and rural areas.

Several factors influence the price of delivering woody biomass to a central location: the type of harvest system, the amount of residual generated as a result of harvest, the distribution of harvest residues within the harvest area relative to the landings, the equipment used for in-woods processing (either grinding or chipping, typically), the equipment used to move the material from the landing to the bio-refinery, and the distance between the harvest site and the bio-refinery. A realistic estimate of the actual amount of renewable and sustainable biomass feedstock over time is essential in developing an accurate market projection for biofuel production that incorporates both economic feasibility and social acceptability. An optimization model of the regional forest products market developed originally at Oregon State University is now being used within the NARA project for this purpose. The model estimates the harvest residual biomass resulting from regular harvest and tracks the amount of biomass economically available for a given (exogenous) price offered at proposed bio-refinery locations.

To promote the rural development goal of the NARA project, there is interest in developing ‘depots’ as a part of a feasible supply chain. Depots are intermediate processing or consolidation centers between the harvest areas and the final bio-refinery. Depots allow for some of the value of the biomass to be captured by more, and more rural, communities than the limited number of locations where a large-scale bio-refinery may be feasible. Developing a framework and modifying the forest products market model in order to consider the economic feasibility of depots within a demand for biomass by bio-refineries was a major undertaking of this dissertation work.

The NARA project focuses on smaller areas within the four Pacific Northwest states to consider specific supply chain logistics. The first year of the project focused on a preliminary analysis in central Idaho, the second on an area known as the Missoula Corridor (northern Idaho, western Montana, and northeastern Washington). However, the scoping analysis for the Missoula Corridor failed to produce a scenario that could deliver the required amount of biomass from harvest residuals for a reasonable price to possible bio-refineries in Libby and Frenchtown, Montana (NARA 2013). The high proportion of federal lands within the study area, along with the low density of biomass in the forests and the low levels of regular harvests in the area, appears to be prohibitive (a discussion as to the importance of federal lands in determining biomass availability is given in chapter 5).

The third study area encompasses the southern portion of Washington and the northern portion of Oregon west of the Cascades and is known as the Mid-Cascades to Pacific (MC2P) region. This Douglas-fir dominated region is extremely productive. Tree size, density, and growth rates surpass that of the eastside, and large amounts of harvest residuals are generated annually as a byproduct of regular, market-driven harvest activities on private lands. To determine potential final refinery locations, spatial data of existing locations of pulp and paper mills, primary and secondary wood processors, biomass energy pellet facilities, and miscellaneous other mill sites was combined with information about road and railroad networks, coarse estimates of county-level biomass density, markets for biofuel, and ownership of forest lands. Guided by stakeholder input and estimates of county-level social acceptability developed from socio-demographic indicators, teams within the NARA project selected final potential bio-refinery sites of Longview and Cosmopolis, Washington for the MC2P region.

1.4 The Scope of This Analysis

This dissertation built on the market model being used in the MC2P analysis of the NARA project that incorporates bio-refinery use of biomass and extended it. Although the NARA project considers only the central part of the westside region, there is no need to *a priori* restrict the possible locations of biomass origin or destination within the region. In the market model, the cost associated with the distance between origins of biomass and destinations determined the forest areas from which it is economically feasible to source biomass. In this way, any plausible region could illustrate the potential for biomass market and depot development in an area around a hypothetical bio-refinery. Nor is there any reason to reject other potential refinery locations that may be interesting for policy analysis.

This work used a market model of western Oregon for analysis with a hypothetical bio-refinery located in Springfield, Oregon, a city with an extensive forest products economy and existing pulp mill. Figure 2 displays western Oregon counties and existing lumber and plywood mill locations. Given the similarity in Washington and Oregon forest products industry, productivity, and harvest practices, results from Oregon with respect to the feasibility of establishing depots were representative of the whole region. Springfield is centrally located within western Oregon and the haul cost of biomass rendered movement of material from adjacent states infeasible. The depot model here developed can easily be scaled to other regions or to the entire westside of Oregon and Washington.

Supply of biomass within the model was determined by the level of harvest of sawlogs within the forest products industry. In this way, biomass was primarily a byproduct of projected harvest activities. The model incorporated an exogenous treatment of pulp chip supply in the region in a similar fashion. The types of material available at harvest – the amount of sawlog, pulp chip, and biomass volumes – were determined by the modeled harvest of current and future tree-level inventory amounts and future projections of volume (the development of this information for the model is discussed in chapter 4, section 4.2). Focusing on the amount of biomass resulting from “business as usual” activities in the existing forest products market provides the most conservative estimate of the amount of biomass potentially available. Collection and utilization of biomass is most economical when it is a by-product of profit- maximizing behavior of private landowners. Western Oregon, due to its high productivity, high levels of profitable harvest, and stable markets, has potential to supply the requisite amount of feedstock to a bio-refinery.

Western Oregon is also interesting to analyze with respect to community effects of a supply chain that includes depots. As noted previously, this region contains many forest-dependent communities and is an area of declining operating mill numbers, employment losses, and social battles over federal forest management priorities. Small towns have frequently suffered with the booms and busts of the forest products industry, and many seek a solution to this through the expansion of the forest products industry.

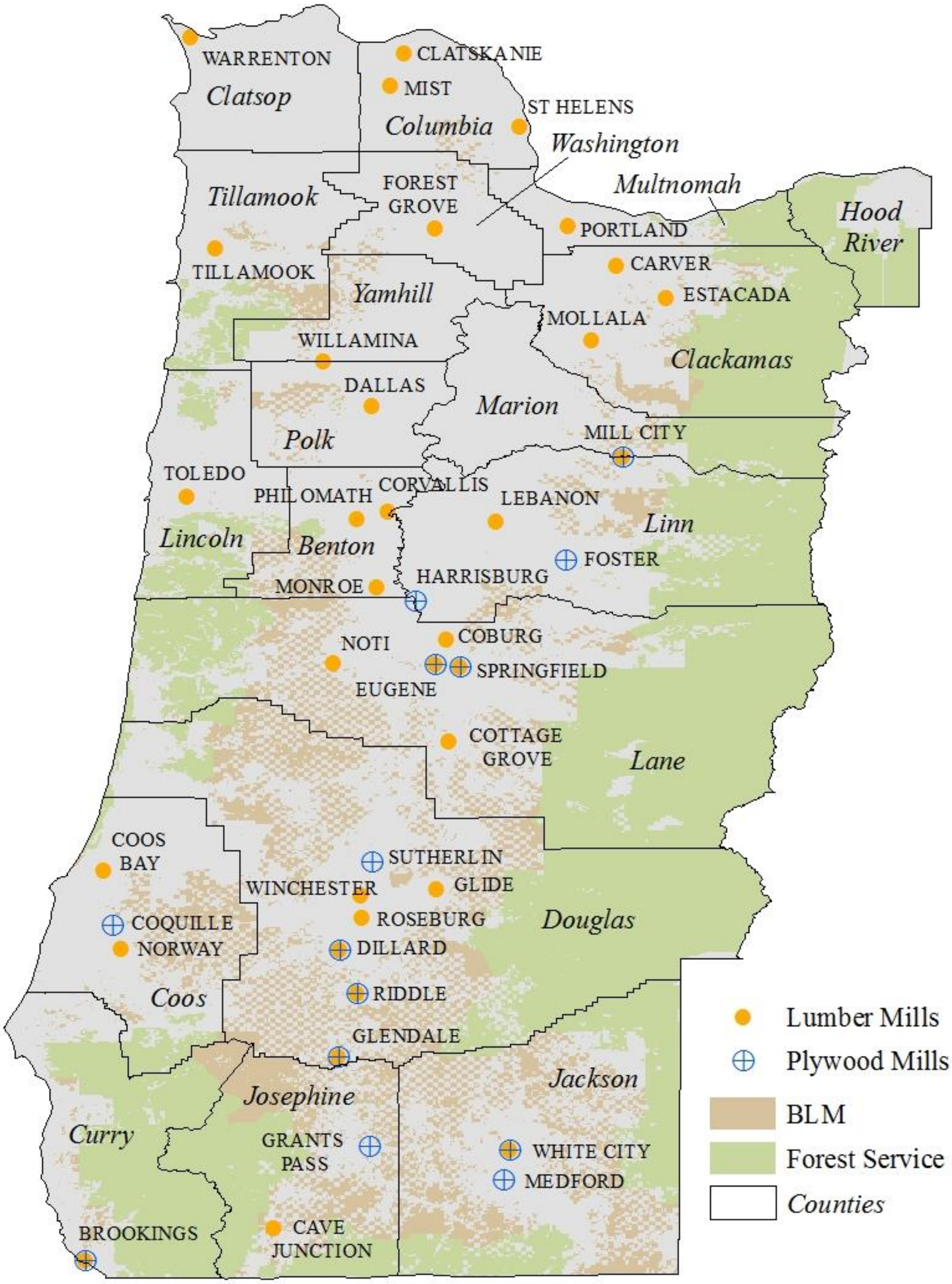

Figure 2. Model region: current demand centers and federal lands.

This dissertation analysis helps to answer the question of whether or not we can hope to achieve better economic outcomes in rural communities through the development of a market for biomass that includes intermediate processing centers designed to both increase the value of the forest product and facilitate rural development. It is, to my knowledge, the first attempt to model the connection of forest harvest practices and a specific rural development strategy within a spatially-explicit, market-driven context. It will address a limitation noted in previous uses of the market model that there are differential impacts of harvest across space that had yet to be analyzed, as well as provide a realistic portrayal of the feasibility of depots as development tools (Adams and Latta 2005).

There is great interest in the ability of the development of a biomass market to stimulate restoration activities and provide incentives for fuel reduction treatment activities on both private and public lands. The market model allows for the inclusion of policy changes in federal land management or of different management activities through the level of exogenous public harvest set or the harvest practices modeled. However, this analysis considered only the current timber harvest levels on public lands and no additional sources of biomass supply from federal lands that might result from restoration activities. There is virtually no fuels reduction treatments being undertaken on the westside, where wildfire risk is relatively low. Restoration may be appropriate in the mixed conifer forests in southwest Oregon, but with limited funds for removal of materials, treatments and restoration activities have typically been focused on the eastern portion of the state. A natural extension of this work is to further develop policy scenarios focused on the potential for wildfire or restoration treatments on federal lands to enter into the biomass supply stream. The analysis did include the potential impacts of increased timber harvest on public lands undertaken to fulfill the allowable cut set in the Northwest Forest Plan, apart from restoration-motivated harvest.

This dissertation proceeds as follows: chapter 2 reviews relevant literature and previous research regarding the role of forest management in facilitating community development and market models of the forest products industry. Chapter 3 describes the existing model as well as the dissertation model developed, the Regional Model of Timber Supply with Emerging Technologies (RMTSET). Chapter 4 outlines the necessary input data for RMTSET, including econometric estimation of input factor demands for lumber and plywood/veneer mills. Chapter 5 discusses the parameterization of the intermediate processing centers or depots developed for RMTSET, and chapter 6 details the model outputs and results. Chapter 7 provides a discussion and conclusion of what these results may indicate for rural communities in the Pacific Northwest.

In all, I explore the connection between rural communities, forest management, and the forest products industry through a market model of regional sawlog supply and demand in order to answer the following research questions:

1. What is the feasibility of western Oregon harvest residues to provide a viable feedstock for the large-scale production of biofuel?
2. What is the feasibility of developing local intermediate processing or collection centers (depots) for biomass?
3. What might be the potential impacts on specific rural communities, in terms of depot longevity and employment, of these increases in both supply and demand for wood fiber?

4. What effects might changes in federal forest policy have on the development of these technologies?
5. Is there potential for development of this type to aid communities most harmed by changes in the forest products industry and/or federal forest policy?

Together, the answers to these questions provide insight into the potential for using non-traditional forest products to stimulate rural development in communities – the ability for a local, stable demand that furthers forest health and community health goals to actually make a difference in specific places in the Pacific Northwest.

2. Previous Research and Literature Review

2.1 Introduction

This dissertation explores the potential for using non-merchantable material as a rural development tool by modeling an increase in both market supply and market demand for the material. Previous research and an appropriate literature review for this idea encompasses two main topics: the potential role for resource management to play in community health and stability, and models of the forest products sector. The first topic is important because this work analyzes critically the realistic potential that forest management and forest products may have on rural communities, a commonly stated reason for developing such markets or supplies. While extensive, this research is far from uniform in either theoretical perspective or in policy recommendations for appropriate resource development vis-à-vis community health and well-being. Section 2.2 explores some of this research thread.

The second topic provides justification for the use of a market model tool to accomplish this. Several previous studies have explored modeling the forest products industry as well as the use of biomass within forest products sector models and are critical steps in the development of this research. Section 2.3 reviews some of these key studies and highlights the differences between previous analysis of forest products markets and this work.

2.2 Community Economics and Natural Resource Dependence

Community economic development theories and resulting policy recommendations have traditionally been driven by Export Base Theory (EBT). Export Base Theory divides the economy into two sectors: the basic, export-driven, goodsproducing sector, and the non-basic sector that supports and is reliant on the basic sector. EBT is a natural extension of neoclassical economics, which posits that development is best achieved through the use of any resource or activity in which a region holds a relative advantage (Freudenburg and Gramling 1994). Development of the basic sector should lead to increased economic activity in the nonbasic sector (Shaffer, Deller, and Marcouiller 2004). This idea of an export base as the foundation and driver of community economies has formed the basis for much of the traditional expected relationship between forest harvest and community health in forest-dependent communities (Figure 3) (J. J. Kennedy, Thomas, and Glueck 2001).

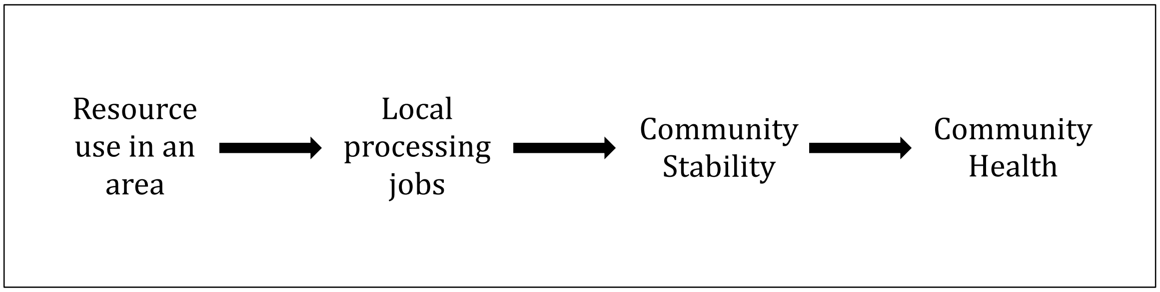

Figure 3. Model of traditional resource extraction and community health.

The notion that regular timber harvest can help stabilize the economic outcomes of communities and people also has a long history and can be traced back to 18th century Germany; the dominance of German management principles in North American forestry naturally led to "the linkage between sustained timber yields and community stability [being] part of the North American foresters' professional inheritance" (Force et al. 1993). Although federal agencies such as the U.S. Forest Service and the Bureau of Land Management are land management agencies, not rural development agencies, the pervasiveness of the view that steady harvest leads to community health can be seen in the goals of forest management plans that have specific community outcomes (Charnley 2006; J. J. Kennedy, Thomas, and Glueck 2001). Research that indicated both that economic declines led to declines in social well-being along with observations that rapid economic growth led to disruptions in social well-being confirmed the desire for economic stability in order to ensure community stability (Kaufman and Kaufman 1946; Freudenburg 1984).

However, dependence on an export base brings with it risk, which cannot be overcome by simply supplying a steady stream of logs to a regional market. These risks are apparent in timber producing regions in the Pacific Northwest. The wood products industry is affected by global market forces and declines in log export markets, domestic demand fluctuations driven by the housing market and changes in interest rates, domestic resource and environmental policies and the exhaustion of old-growth, and technological change (Weber 1995; Adams and Montgomery 2013). The idea that community health can be sustained through sustained harvest ignores the demand side of the forest products market. Increases in supply of stumpage in the absence of increased demand simply push down prices, creating a disincentive for further supply, until the market again reaches equilibrium (Adams and Montgomery 2013).

The notion that harvest can sustain economic growth or positive outcomes has also been questioned after observation of poor community outcomes in areas of natural resource utilization. Theories explaining a “resource curse” range from economic (rational underinvestment, industrial structure and segmentation) to sociological (power-based theories and social constructions of nature) (Stedman, Parkins, and Beckley 2004;

Slack and Jensen 2004; Nord 1994). New Economic Geography models, which provide a theoretical framework for declines in regions as a function of initial conditions or critical thresholds in key development factors such as transportation costs, have lent support to the idea that economies can struggle despite being rich in natural capital. Documented labor market disadvantages (higher prevalence of underemployment) faced by workers both in extractive industries and in non-metropolitan areas in general argue that increases in resource development may not necessarily lead to better employment conditions (Slack and Jensen 2004; Findeis and Jensen 1998). This was demonstrated in the Pacific Northwest following the 1980s recession. Even as harvests and lumber output ramped up, employment did not keep pace; efficiency gains in capital and the closures of less efficient mills has resulted in overall declines in full-time equivalent employment per harvested amount (Cook 1995; Greber 1993; *Oregon Business* 2006; Humphrey 1990; Helvoigt, Adams, and Ayre 2003).

Observations of increased production with concurrent employment declines, along with studies that failed to show connections between harvest levels and community outcomes or federal changes in timber management practices and local employment conditions, led many to question this dominant model of resource extraction and economic development (Freudenburg, Wilson, and O'Leary 1998; Donoghue and Haynes 2002; Berck et al. 2003). Studies exploring the fates of western rural communities observed two conflicting trends: declines in natural resource-based sector growth and employment levels, following a nationwide trend towards increased service sector employment, and high growth in population, income, and/or employment in certain high amenity areas (Freudenburg, Wilson, and O'Leary 1998; Hansen et al. 2002; Charnley

2006; Rosenberger, Sperow, and English 2008; Ferguson et al. 2007; Deller et al. 2001; Power 2006; Beyers 1991; K. M. Johnson and Beale 2002). This is the idea of community economic development that is driven by environmental quality and in-migration rather than resource extraction and utilization (Figure 4) (Winkler et al. 2007). The contention over the role of forests in community development and the debate over the effects of decreases in harvest on rural communities have become especially focused on these two models, with either side using one as a basis for advocating for increases or decreases in harvest to improve community conditions.

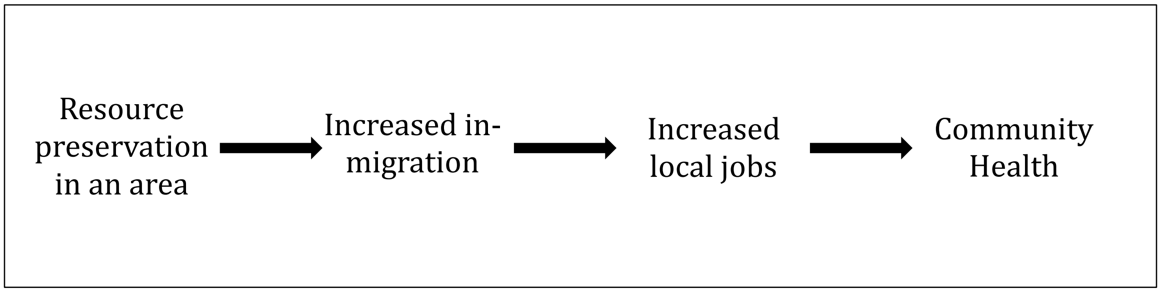

Figure 4. Model of resource preservation and community health.

However, is amenity-driven migration really a potential answer to the problems seen in forest-dependent communities? Many researchers have looked for connections between changes in management or resource extraction (including designation of wilderness areas, national parks, and national forest management changes in the form of the Northwest Forest Plan) and subsequent community levels of well-being or economic or employment effects, with mixed results (Charnley 2006; Charnley, Donoghue, and Moseley 2008; Rosenberger, Sperow, and English 2008; Lorah and Southwick 2003; Chen and Weber 2012; Lewis, Hunt, and Plantinga 2002). Amenities clearly influence regional economies and personal migration decisions, but public land preservation (e.g. wilderness designations) as a specific driver for local economies or increasing employment has not been shown to be significant (Eichman et al. 2010; Lewis, Hunt, and Plantinga 2002; Duffy-Deno 1998; Keith and Fawson 1995). There is evidence that the communities that have experienced the most success with amenity development were the least resource-dependent to begin with and that the effects of amenity-driven growth dissipate after an initial adjustment period (Eichman et al. 2010; Chen and Weber 2012; Rosenberger, Sperow, and English 2008; Hansen et al. 2002). In addition, employment growth and net migration may be jointly produced, and employment gains due to net migration increases may not be enough to offset the employment losses from the loss of the extractive industry (Eichman et al. 2010).

The potential for rural development in resource-rich areas is perhaps best seen as a blend of use and conservation strategies, while acknowledging that both bring significant risk of cyclical and fluctuating employment conditions (Keith, Fawson, and Chang 1996; J. J. Kennedy, Thomas, and Glueck 2001). In fact, given the reality that the same forested landscape provides the raw materials for either timber-based or amenity-based development, most communities already have a mix of strategies and economies present. While this dissertation does not compare the potential outcomes between these two different rural development strategies, it can provide some evidence for whether or not market and resource use based strategies may provide help to rural communities and provide a counter to those who advocate only one type of development.

One persistent question in rural development in general is: Why pursue it at all? In an-ever changing world and economy, communities will naturally grow and shrink.

This is the market system in action: flows of people and capital will move to where the most profitable use is. However, I believe there are several economic and ecological reasons why we should be concerned about the fates of rural resource-dependent communities, and where community development is justified. Rural communities may have non-market values in and of themselves, such as existence and option values, for all people. There may be market failures due to externalities that drive some declines or advantages in specific places. If one considers equity as well as efficiency, some rural communities have borne the brunt of changing societal expectations. The costs and benefits of changes in market demand and supply, and changes in forest and environmental policy, are not borne out equally among all places. During an almost 20 year period in Oregon, 33% of large sawmills closed, but over 85% of small sawmills closed – located predominately in rural areas (Freudenburg, Wilson, and O'Leary 1998). And finally, long-term residents of rural resource-based places may have traditional ecological knowledge that can help guide more integrated, holistic resource management. Natural resource and older workers tend to be more tied to the land, and this tie is important for the well-being of people, the community, and for the land (Kusel et al. 2000; Helvoigt, Adams, and Ayre 2003). Higher risk of underemployment and unemployment in these fields, coupled with place attachment, indicates less labor mobility and social flexibility for some populations. The loss of that local knowledge through loss of communities or through displacement of residents may lead to both short-term pain for the people involved as well as long-term impacts on community function and natural resource management.

2.3 Models of the Forest Products Market and Biomass Use

Modeling the forest products industry began in the United States in the 1950s, typically with the use of econometric methods (Buongiorno 1996; Adams and Blackwell 1973). In later years, economists pursued more complete models of the entire forest sector, and adopted techniques from management sciences such as linear programming to predict optimal forest products markets. Systems approaches have been explored more recently, where change is described without relying on inter-temporal optimization (Buongiorno 1996). Forest sector models are either static or dynamic. Static models project market activity and equilibrium one period at a time, while dynamic models determine market equilibria for the entire projection period in one solution (Adams and Montgomery 2013). Frequently, the model is maximizing the total discounted social welfare or market (consumer and producer) surplus in order to identify the equilibrium price endogenously, following Samuelson’s observation that in a spatial equilibrium, the price that clears the market is the price that maximizes market surplus (Adams and Montgomery 2013; Buongiorno 1996; Samuelson 1952). Forest products sector models vary also in their treatment of how timber harvest is allocated in time and space, how investment is considered, the spatial detail of the resource and the industry, the representation of processing, and the links between the forest industry and other sectors (Adams and Montgomery 2013). Most models of the forest sector have been focused on the markets for well-established outputs such as lumber, plywood, or paper; few have incorporated the use of non-merchantable material such as biomass.

Utilization of that material, however, is not a new or novel idea. In the early days of the United States, fuelwood represented 91% of the total energy supply, and extensive use of biomass for electric or heat generation is common currently in some northern European countries (Bain and Overend 2002; Daugherty and Fried 2007). Development of stand-alone biomass electrical plants occurred in California in the 1980s; however, the price of woody biomass as a feedstock has not been competitive with fossil fuels. Although frequently used within sawmills and veneer mills as a fuel source for dryers, biomass use outside the forest products industry has failed to be widely adopted (Nicholls et al. 2008; White 2010; Bain and Overend 2002). What is new is the recent interest in removing non-merchantable material to further both ecological and social community conditions. This has led to many studies exploring the potential for this material to accomplish these goals while remaining as economically feasible as possible (Daugherty and Fried 2007; Nicholls et al. 2008). Some of these adopt more traditional forest market models to do so.

Assessing the feasibility, optimal use, and implications of the use of biomass is complex. Unknown parameters include the efficient size of bioenergy facilities, the optimal locations of facilities, the amount of biomass available at varying levels of spatial specificity, the cost in obtaining the biomass, and the potential feedback effects on larger forest products markets. Analyses of the feasibility of biomass use frequently focus on only one or two of these considerations in order to make the problem tractable. These efforts can be grouped into three categories: models using detailed inventory information with limited market interactions, spatial equilibrium models with aggregate supply and demand information, and regional dynamic spatial equilibrium models with detailed inventory and/or demand information. The major factors of these modeling approaches are given with examples of studies in Table 1 and are summarized in this section.

Table 1. Major approaches to modeling fuel treatments and forest products markets.

Source	Geographic area	Model Specifications	Supply	Demand
Abt and Prestemon, 2006.	12 western states. 3 demand markets: local, western Canada, rest of the world (including east US).	Spatial equilibrium market model of 12 states and trading partners. Objective: maximize PS + CS; max acres treated. Outputs: solved for annual removals over a 5-year period.	13 forest types that supply 4 softwood products: ponderosa & sugar pine timber, lodgepole pine timber, other softwood timber, softwood chips. Chips price exogenous. Supply from western biomass assessment: volumes and acres by species group by state. Proportioned out to acres in WUI and acres in 3 fire condition classes. Nonspatial, no growth.	Sawlogs only. Base mill capacities and production levels from Spelter and Alderman (2003).
Ince, Spelter, Skog, Kramp, and Dykstra, 2008.	12 Western states. 8 supply regions (Coastal PNW, East OR, East WA, CA, ID, MT, WY and SD, Four Corners) 3 demand regions (US West, US East, Export).	FTM-West, a price endogenous linear program model built on PELPS. Objective: maximize consumer + producer surplus. Outputs: annual market equilibria (prices and quantities) of consumption and production for all demand products, 1997 – 2020.	4 supplied products: pine timber, non-pine timber, logs, chips (outputs of harvest or thinning). Supply curves estimated for conventional supply in each region. Public supply exogenous policy variable. All modeled as inputs by seven tree size classes based on DBH.	8 demanded products: softwood lumber, softwood plywood, poles and posts, paper, paperboard, market pulp, hardboard, fuelwood. Demand curves estimated.
Latta and Adams, 2005.	Eastern Oregon supply and demand (exports included at 25%, exogenous).	Dynamic spatial equilibrium model, solved with mixed-integer linear program. Objective: maximize consumer + producer surplus + final land and timber value.	Private and public timber supply of sawlogs. Silvicultural and harvest decisions are endogenous. Inventory modeled at the condition class level within plots. Management options are grouped by intensity classes. FVS used to grow future stands. Public logs exogenous. Thinning program is 20 years.	Mill-level demand from regional econometric estimates of demand portioned out using mill-level capacity estimates.

Table 1 (continued). Major approaches to modeling fuel treatments and forest products markets.

Source	Costs/Prices	Fuel Treatments	Capacity	Results
Abt and Prestemon, 2006.	Prices from cut & sold reports, adjusted to reflect regional harvests. Treatment costs use STHarvest model to assess cost of removing small-diameter timber by state and forest type. Between-region trade also assigned costs; distance is average to mill for that state.	Treatment applied to all 13 forest types and 3 condition classes – reduce volume to 30% of max SDI, removing from all size classes.	Capacity utilization is limited to 1.3 times current production, and must be at least .45 times current production. Harvest cannot increase by more than 30% a year. No direct capacity/investment decision.	Effect of treatment program on private timber is negative, and reduces overall SNW (cost to taxpayers of subsidy is included). With state-level restrictions, acres treated declines. Restricting treatments to the WUI increases SNW.
Ince, Spelter, Skog, Kramp, and Dykstra, 2008.	Harvest costs for fuel treatments from FTE 3.0.	Compares a thin-from-below to a SDI-based program of treatments, with and without subsidies (no admin cost + subsidy of \$5.66/m^3 removed to admin cost of \$1250/ha). Estimates of areas treated and costs from Fuel Treatment Evaluator (FTE) 3.0, which selects plots to treat based on FIA data.	Initial capacity estimates based on Spelter and Alderman (2005). Capacity change projected with a representation of Tobin's q model; regional capacity change a function of the ratio of shadow price of capacity to cost of new capacity.	Expanded supplies from fuel treatments may displace private supplies, with decline in timber prices. Increases in CS, declines in PS uniformly; overall increases in net market welfare under SDI treatments.
Latta and Adams, 2005.	Transport costs from source to destination are explicit. Harvest costs use Fight, Gicqueau and Hartsough model to roadside.	Treatments reduced SDI on plots where it currently exceeds 75% to 50% of maximum, TFB. Only non-zero board foot volume removals considered. Subsidy is the cost of removing all non-merch material in thinnings, with no stumpage cost.	Decisions to maintain, expand, contract or close processing centers is endogenous. Minimum operating capacity in each period, plus minimum investment to entry. Quasi-fixed in short run; can expand in long run.	Harvest of public timber extends mill lives. Without thinning, harvest declines and mills close while inventories recover. With thinning, the harvest trough is moved out 30 years.

The first group of studies consists of those utilizing detailed supply information or detailed information about bioenergy facilities in the absence of larger market effects. The simplest studies estimate the effects of harvest to reduce fire risk and focus on the costs to remove material or simple cost/revenue models of the benefits of the activity (Keegan et al. 2002; Keegan III, Fiedler, and Morgan 2004). Without considering larger market effects within the forest products industry, however, projected benefits may be greatly overstated. Studies focused on the optimal biomass facility size or location typically must use less detailed resource information in order to solve the problem, such as county level estimates of biomass or assumptions about uniform distributions of the forest resource. Still, given likely cost curves and GIS information about roads and cities, facility locations can be optimized (Jenkins and Sutherland 2014; Zhang, Johnson, and Sutherland 2011).

This group of studies also includes models using FIA BioSum (Forest Inventory and Analysis Biomass Summation), a geographic analytical framework for assessing biomass production from fuel treatments developed by the US Forest Service (Daugherty and Fried 2007). BioSum, along with the detailed stand information and management prescriptions developed by the modeler, can optimize treatments across the landscape and project biomass recovered (Barbour et al. 2008). By combining these estimates of biomass supply at the Forest Inventory and Analysis plot level (section 4.2) with specific potential facility locations to utilize the material and estimates of harvest and haul cost, Daugherty and Fried (2007) optimize the location of hypothetical biomass energy plants in the southwest Oregon/northern California region. However, this approach is not a market approach. Although this use of BioSum is able to simultaneously optimize the best fuel treatment on each acre and the best locations and capacities for bioenergy development, the potential effects of this use on other aspects of the forest products market are not considered, and demand is not explicitly modeled at the receiving end of any product generated from BioSum (biomass or sawtimber). All prices are exogenous. As such they are of limited use in understanding the connection between profit-maximizing timber harvest and potential biomass use, or the effects of changing levels of public harvest on private supply and market prices.

The second and third groups of models have in common a market-based approach with features such as endogenous price determinations for sawlogs and changing capacity over time in the industry. Most of these studies have developed specific adaptations of PELPS, the Price Endogenous Linear Program System, or of a market model developed primarily by Darius Adams and Greg Latta at Oregon State University. Both maximize consumer and producer surplus over the modeling horizon in order to simulate the forest products market. Differences between the two include the level of detail about the resource supply, the static or dynamic nature of the solution, and the extent of area modeled.

PELPS operates in both a static and dynamic phase: the static phase determines the annual or periodic equilibrium in markets, while the dynamic phase adjusts capacity based on the value of the capacity resulting from the static phase (Buongiorno 1996). The PELPS-based studies cover large areas with detailed demand information for the forest products industry and less detailed supply information of the forest resource (Abt and Prestemon 2006; Ince et al. 2008). Changes in the resource over time may not utilize growth and yield models, but instead simply adjust volumes forward using recent growth rates in the region (Ince et al. 2008). These studies have produced estimates of the net market impacts of different types of fuel-reduction treatments and of maximizing different treatment goals (Ince et al. 2008; Abt and Prestemon 2006). Additional studies that build on these have utilized an expected net economic benefits framework or a goal programming framework to address even larger regional and inter-regional effects (Prestemon, Abt, and Huggett Jr. 2008; Prestemon, Abt, and Barbour 2012). All of these have considered the potential market impacts of changes in harvest resulting from fuels-reduction treatments.

Regional dynamic spatial equilibrium models of the type employed by Adams and Latta capture some aspects of both of the previous classes of models (Adams and Latta 2004; Adams and Latta 2005; Adams and Latta 2007; Adams et al. 1996; Latta and Adams 2005). By maximizing consumer and producer surplus at a small regional level (e.g. eastern Oregon), the model is able to use spatially explicit and detailed supply and demand information, while still considering the effects of activities on the overall regional forest products market or the market impacts of changes in public management. The model has also been used to assess the cost associated with different management regimes: for example, the cost associated with lengthening rotation ages in order to provide old-forest structure or the potential impacts of changes in federal timber harvest on regional carbon sequestration (Im, Adams, and Latta 2010; Montgomery, Latta, and Adams 2006).

Tree-level data are used to model timber growth and inventory. Tree list information in conjunction with equations can be used to calculate estimated physical biomass in any number of material pools, such as the amount in the main stem (merchantable) or the amount in tops and branches. Management regimes are developed in advance, including fuel or restoration treatments, but the model determines the optimal management regime for any given acre (including timing of final harvest for even-aged systems). Growth and yield models of tree and stand development are used to project the volume of standing material and the volume of material removed for every possible management prescription on every forest acre. Demand for logs (stumpage) is modeled at the mill or milling center level, based on capacity estimates derived from current conditions and econometrically estimated factor demand elasticities; supply of logs is determined by the cost of providing timber for harvest at any given point in time. Mill or milling center capacity investment decisions are determined endogenously, as is the supply and price of logs available in each period; the supply of timber is determined by the cost of providing timber to harvest at any given time in comparison with the price mills are willing to pay for timber. So far, the model has been used only to assess the regional sawlog and veneer/plywood market, with pulpwood chips modeled with exogenous prices and perfectly elastic demand at known pulp mill locations.

Key elements of these models are the spatially explicit nature of both the supply source and the demand destination of the material. The cost to transport the material between the source and destination can be estimated with either straight-line distances or known road networks, and the resulting cost plays a large role in determining the timber shed for any given mill or milling center. In addition, the approximate location of harvest over the modeling horizon can be mapped. Capacity is adjusted incrementally by period at each mill or milling center based on the optimal solution for all periods. Limitations of the model, and all dynamic models, include: (i) an inability to simulate history and (ii) the condition of perfect foresight over the projection period, and thus no explicit inclusion of uncertainty (Buongiorno 1996; Adams and Montgomery 2013).

Few of these models have incorporated biomass as an additional supply and incorporated estimates of emerging technologies that can drive biomass demand within a market framework. There are several advantages to adapting the Adams and Latta market model in order to do this. One is the highly detailed spatial nature of the supply and demand locations. If using this material to promote or enable rural development is a goal, then it is essential that the model predict actual locations in which it is economically feasible, as well as accurately estimating the location of available biomass. When solved as a mixed-integer program rather than a linear program, the model can track establishment and closure of specific mill or biomass processing sites over time (Adams and Latta 2005). A second advantage is that biomass supply is modeled as it actually occurs, as a byproduct of current sawtimber harvest activity. By allowing market conditions for a known, profitable, stable industry to drive biomass availability, it limits the risk of over-estimating the material that can be profitably removed from the woods. Finally, the use of growth and yield models in conjunction with known harvest and management practices to develop estimates of biomass over time produces results that reflect likely conditions in the future. As an example, the current overstocked conditions on federal land mean that, for fuel-reduction treatments, the initial entry will remove higher volume than subsequent entries. Estimates of biomass availability that rely solely on current conditions do not reflect this dynamic aspect of the resource. This dissertation is the first attempt to model biomass supply as a by-product of current harvest with specific emerging technologies and to evaluate the effects of this market-driven system with respect to rural communities.

3. Economic Theory and Model Description

3.1 Introduction

The model used for this project is an adaptation of the regional dynamic spatial equilibrium model of timber supply and demand developed at Oregon State University and used in previous studies (Adams and Latta 2005; Latta and Adams 2005; Montgomery, Latta, and Adams 2006). In order to model the potential effects of emerging technologies in biomass use on rural communities, I added additional supply factors and additional demand factors into the base model. In this discussion I refer to the previously-used model as RMTS (regional model of timber supply) and the expanded model as RMTSET (regional model of timber supply with emerging technologies). RMTS models the forest products market primarily as the competitive, profit-maximizing interactions of individual firms and landowners. RMTSET incorporates the use of biomass for jet fuel at a bio- refinery (the goal of NARA); RMTSET with extensions includes the development of intermediate processing facilities (depots) to better assess the potential for biomass use to assist rural communities. This chapter details the relevant theory of the firm, provides an overview of the forest products market that RMTS/RMTSET simulates, and describes all three models.

Of particular importance to RMTS is the relationship between profit, input factor demands, and investment decisions at the firm level. Producer and consumer surplus is maximized by modeling individual mill level demand for the main input factor in the milling process (stumpage) sold by forest landowners and by incorporating mill capital adjustment over the planning period. The basic theory of the firm can be used to understand input demand and investment behavior at the mill level, and is discussed in section 3.2. An overview of the specific nature of the forest products market is given in section 3.3. A description of the base model is detailed in section 3.4, and mathematical representations of the base model RMTS, RMTSET, and RMTSET with extensions are covered in sections 3.5, 3.6, and 3.7, respectively.

3.2 Investment and Factor Demands at the Mill Level

Suppose a representative firm produces one output, q, and uses three primary inputs. The output is lumber, and of the inputs, two are variable (labor L and sawlogs S) and one is fixed in the short run (capital, K)[1]. Each input has per-unit costs associated with the utilization of the input: wages w for labor, investment v for capital, and raw material cost c for logs. Production of q in time t is a function of the level of inputs:

$$q_t = f(S_t, L_t, \overline{K}) \tag{1}$$

The firm's profit at time t is simply the difference between income received from the sale of q at price p, minus the current costs of the input factors. Substituting the production function in for q results in the following:

$$\pi_t = p_t f(S_t, L_t, \overline{K}) - c_t S_t - w_t L_t - v_t \overline{K} \tag{2}$$

The firm's short-term problem is to choose the levels of variable inputs that will maximize profit, given current capacity, the current prices of the output, and the current prices of the inputs:

$$\max_{S,L} \pi_t = p_t f(S_t, L_t, \overline{K}) - c_t S_t - w_t L_t - v_t \overline{K} \tag{3}$$

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[1] Although this is a simplification of the milling process, it's not unreasonable. Raw materials, labor, and capital comprise the bulk of milling costs over other variable inputs (e.g., energy), and capital is difficult to adjust in the short run.

Solving for the first order conditions provides the optimal levels of inputs as a function of prices and capital:

$$p_t f_{S_t} - c_t = 0 \quad \rightarrow S_t^*(w_t, p_t, \overline{K}) \tag{4}$$

$$p_t f_{L_t} - w_t = 0 \quad \rightarrow L_t^*(w_t, p_t, \overline{K}) \tag{5}$$

The optimal level of output q is a function of the optimized levels of inputs:

$$q_t^*(w_t, p_t, \overline{K}) = f\left(S_t^*(w_t, p_t, \overline{K}), L_t^*(w_t, p_t, \overline{K})\right) \tag{6}$$

By substituting the optimal levels of output and inputs into the original profit function, we have the indirect profit function, the optimal profit given prices and a fixed level of capital:

$$\Pi_t(w_t, p_t, \overline{K}) = p_t q_t^*(w_t, p_t, \overline{K}) - v_t\overline{K} - \ c_t S_t^*(w_t, p_t, \overline{K}) - w_t L_t^*(w_t, p_t, \overline{K}) \tag{7}$$

At the point $q_t = q_t^*(w_t, p_t, \overline{K}_t)$, Hotelling's Lemma provides the theoretical basis for capturing factor demand equations from the profit function; the derivative of the optimized profit function with respect to each price provides the optimal factor demands (Nicholson and Snyder 2011; Chambers 1988):

$$\frac{\partial \Pi_t(w_t,p_t,\overline{K})}{\partial p_t} = \ q_t^*(w_t, p_t, \overline{K}) \tag{8}$$

$$\frac{\partial \Pi_t(w_t,p_t,\overline{K})}{\partial c_t} = \ -S_t^*(w_t, p_t, \overline{K}) \tag{9}$$

$$\frac{\partial \Pi_t(w_t,p_t,\overline{K})}{\partial w_t} = \ -L_t^*(w_t, p_t, \overline{K}) \tag{10}$$

Thus, even if we cannot empirically observe individual profit functions, the region-wide demand for stumpage (logs) as a function of current prices and industry capacity can be derived from estimates of industry profitability. The estimates of log demand elasticity that are a key input into RMTS and RMTSET rely on this model of firm behavior in the short run and on the ability to recapture input demands from profit estimates (the necessary inputs to the model and the estimation process for log demand elasticities are detailed in Chapter 4).

Although the amount of capital equipment is fixed in the short run, it is variable in the long run as a result of both depreciation and investment (capital is often referred to as *quasi-fixed*), another feature incorporated into RMTS and RMTSET. The firm's long run problem incorporates this evolution of capital over time.

Suppose each unit of capital investment costs z_t. The firm's value is the net present value of earnings over time, including the costs of variable inputs and the costs of investment:

$$V_0 = \sum_{t=0}^{T} (p_t f(S_t, L_t, K_t) - c_t S_t - w_t L_t - z_t I_t) e^{-rt} \tag{11}$$

where r is the real discount rate. Capital stock K in time t is a function of previous capital stock, depreciation δ, and investment I_t. The equation for capital adjustment incorporates all of these factors:

$$K_t = K_{t-1} e^{-\delta} + I_t \tag{12}$$

This equation describes the evolution of capital over time. Rearranging gives an equation for investment in time t:

$$I_t = K_t - K_{t-1} e^{-\delta} \tag{13}$$

Substituting for I_t imposes the constraint of the evolution of capital over time, and the value function now reflects the three choice variables available to the firm in the long run. The firm chooses capital, labor, and stumpage in order to maximize the net present value of the firm:

$$\max_{S,L,K} V_0 = \sum_{t=0}^{T} (p_t f(S_t, L_t, K_t) - c_t S_t - w_t L_t - z_t (K_t - K_{t-1} e^{-\delta})) e^{-rt} \tag{14}$$

Solving the producer's maximization problem with the value function, subject to the capital stock evolution equation, results in the following system of first order conditions:

$$\frac{\partial V_0}{\partial S_t} = \left(p_t f_{S_t} - c_t\right)e^{-rt} = 0 \ \rightarrow \ S_t^*(p_t, c_t, w_t, z_t, r) \tag{15}$$

$$\frac{\partial V_0}{\partial L_t} = \left(p_t f_{L_t} - w_t\right)e^{-rt} = 0 \ \rightarrow L_t^*(p_t, c_t, w_t, z_t, r) \tag{16}$$

$$\frac{\partial V_0}{\partial K_t} = \left(p_t f_{K_t} - z_t\right)e^{-rt} + z_{t+1}e^{-\delta-r(t+1)} = 0 \ \rightarrow \ K_t^*(p_t, c_t, w_t, z_t, r) \tag{17}$$

Along the optimal path, the marginal cost of adding additional capital must equal the present value of increased productivity over time. The dynamic view of capital adjustment presented above follows generally flexible accelerator models for quasi-fixed input factors (Galeotti 1996). This view of firm value and of capital adjustment over time provides the basis for the establishment of new processing facilities in rural locations as well as expansion of current capacity at individual mills within RMTS and RMTSET. Change in capital over time within the model incorporates depreciation and investment decisions.

3.3 The Forest Products Market

The forest products market sector transforms standing trees into end products for consumer use (lumber, paper, and panel products). Within this sector, there are three market levels: the log market, the intermediate wood products markets, and the final wood-using products markets.

The log market covers the conversion of standing trees into logs. Supply of stumpage (trees on the stump) is generated from forest owners with mature timber, who offer up timber sales to loggers. Timber harvest (logging) converts the standing trees to logs and chips, delivered to sources of demand (mill sites). Market-level supply of stumpage is affected by changes in ownership of forest land, conversion of forest land to other uses, changes in management intensity or goals (for example, a decline in harvest offered from public lands in response to species preservation concerns), and by the current level of inventory. Standing inventory in any one time period equals the inventory in the previous period, minus harvest between periods, plus growth between periods. Log supply to any one mill or processing center depends on attributes of the forest inventory and the conversion costs (the in-woods harvest costs and per-unit haul costs between the woods and the mill).

At the mill, the intermediate wood products market, logs are converted into wood products (lumber, plywood, or veneer) or chips are converted into paper or engineered wood products, or used for energy or heat production[2]. Individual mills demand raw material inputs (logs and chips) as a function of the demand for wood products, labor and other input costs, and their current capacity to process material.

Figure 5 shows a possible short-term mill level supply and demand interaction for one mill *i*. At an individual mill level, supply is limited by cost of transporting materials, creating a ‘timber shed’ *j* around each mill. Beyond each timber shed, it is not cost-effective to transport material to the mill. As the price offered for logs increases, private landowners will offer more timber for sale (and the geographic area in the timber shed will increase concurrently, assuming that costs do not increase proportionally). Public

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[2] Chips are used in the manufacture of oriented strand board as well, but this is a minor or nonexistent component of usage in the regions of the Pacific Northwest that will be modeled. Sawdust is used in the production of particleboard and medium-density fiberboard in our area, but the source is typically from mill residues.

land managers do not maximize profits, so it is assumed that public offerings of stumpage are not affected by price. The overall supply of timber within a timber shed is the combination of these two supply streams.

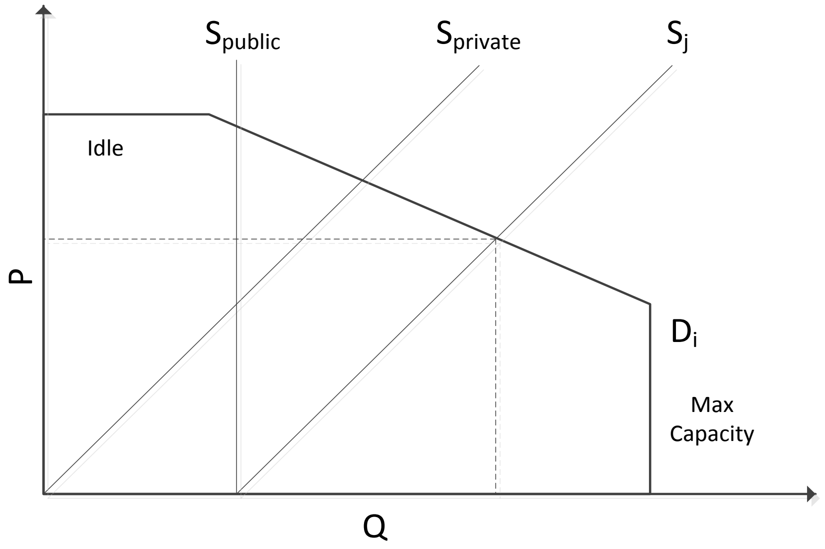

Figure 5. Mill-level supply and demand interactions as modeled in RMTS.

Mill demand for stumpage in the short term is constrained by two conditions: a minimum level of output below which it’s too costly to operate, and a maximum level of mill capacity. The relationship between mill costs, market price for output, and production decisions for a price-taking firm in the short run is shown in Figure 6 (adapted from Nicholson and Snyder 2011). A price-taking firm in the short run produces output where marginal costs (MC) equal the market price of the product; higher prices induce more output. Changes in input costs (e.g., price of logs) shift short-run marginal cost and variable cost curves, changing production decisions. For prices below the average variable cost (AVC), the firm produces no output. In Figure 6, the weighted lines are the firm’s short-run supply curve. For example, a large enough rise in the cost of logs shifts the average variable cost curve up, possibly resulting in a zero-output decision for the same market output price. Mill capacity utilization levels (as a percent of total potential capacity) change over time with changes in costs of variable inputs.

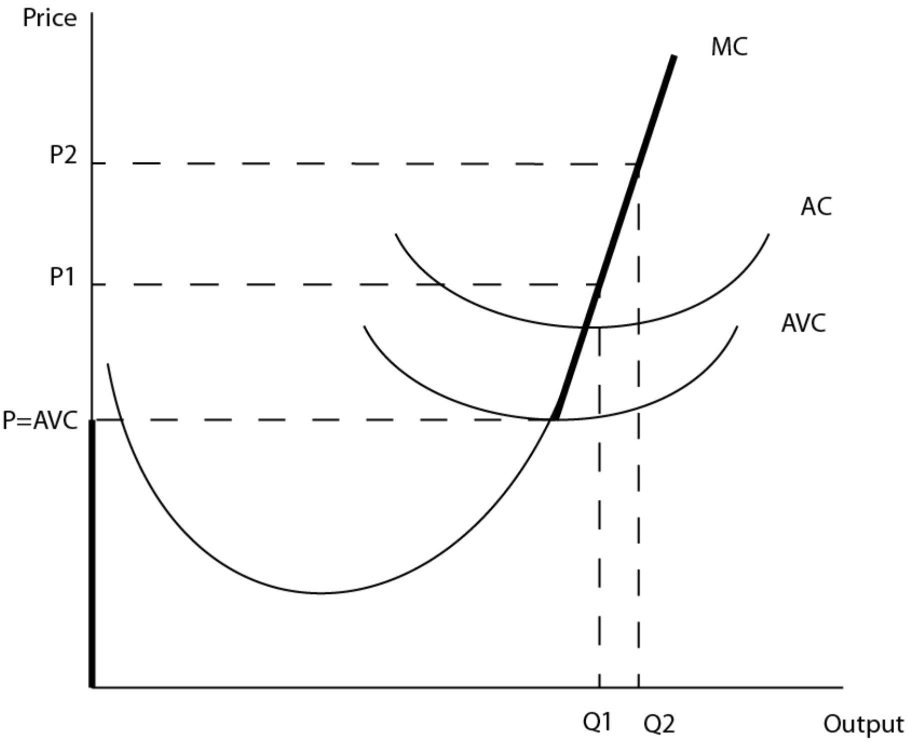

Figure 6. Short-Run Supply Curve.

In the long run, mill capacity is adjustable through investment. Mills repeatedly constrained by capacity or with expectations of greater future stumpage supply can invest in new processing capacity, or investors can establish a mill in a new location. These conditions hold for both sawmills as well as veneer and plywood mills.

Finally, mills supply wood products to consumers in the final wood-using products markets. Timber demand is thus derived demand: it is derived from the demand for the final products, whether consumables such as paper, tissue, and cardboard or durables such as houses. Demand for housing induces a demand for lumber and plywood. The demand for lumber and plywood then induces a demand for logs, which motivates investors or landowners to grow trees to harvestable size and offer stumpage onto the timber market.

3.4 General Description of the Base Model

The RMTS integrates the log and mill levels of the forest products market in a dynamic model based on the economic theory of profit-maximizing behavior of firms. Landowners are producers (suppliers of stumpage) and mills are consumers (demanders of stumpage). The objective function of RMTS maximizes producer and consumer surplus over the time horizon by maximizing the sum of all discounted mill-level willingness to pay for logs minus producer costs, plus the future timber returns at the end of the projection period (modeled as the net surplus under continued forest management at a level set to the average harvest over the projection period).

In the model, the price that logs receive at the mill is determined endogenously. The price is set at the intersection of supply and demand in each period, moving forward from known initial levels of price and quantity. Changes in price in later periods are a result of changes in inventory and harvest (supply) and changes in milling capacity (demand). Elasticity of demand at the mill level shifts price according to changes in quantity consumed, representing movement along the demand curve.

Demand for final wood products by consumers is not explicitly modeled; the final product price of lumber and plywood/veneer is exogenous to the model, and all lumber or plywood/veneer products produced by mills are sold. The model does incorporate projected changes in the main factors that shift demand for lumber over time, e.g., changes in population. The underlying assumption is that regional production of lumber and plywood/veneer is unlikely to have an impact on overall North American supply and prices of the finished products under the scenarios modeled.

RMTS optimizes consumer and producer surplus by choosing two control variables representing supply and demand: the area allocated to different management regimes and the level of investment in capacity at the individual mill level[3]. Acres within each inventory unit are allocated to either an uneven-aged management regime or an even-aged management regime. Uneven-aged management regimes are harvested periodically over the life of the model. Acres assigned to even-aged management regimes follow any one of several regimes for intermediate treatments, while the timing of the final regeneration harvest is selected by the model. Mill capacity can increase incrementally from known starting capacities in each period if the investment chosen by

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[3] There are far more mills in western Oregon and Washington than in the areas east of the Cascades (eastern parts of these states as well as Idaho and Montana). It is also more likely that there are several mills in one location on the Westside. RMTS for the Westside of Oregon and Washington does not model individual mills, but rather groups of mills as processing centers. This creates an important distinction in the actual model: on the Westside, capacity adjustment occurs at the processing center level and is continuous (processing centers do not shut down). On the eastside, capacity adjustment is discrete, with mills shutting down over time; this creates a mixed-integer model. The discussion of RMTS in this proposal focuses on the eastside version, because the intermediate processing investment decisions within RMTSET with extensions forced a mixed-integer model regardless of region.

the model contributes to maximizing consumer and producer surplus over the entire planning horizon. In this way, harvest timing, silvicultural decisions, and mill-level investment decisions are endogenously determined, along with the price of logs.

Each forest inventory unit (condition class) incorporates information about species mix, structural characteristics, site conditions, and plot location. Management prescriptions detail potential silvicultural activities that can be undertaken for each inventory unit over the projection period, $t=0,\ldots,T-1$, where t represents 5-year increments. The prescriptions vary by forest type, land owner type, region, and any other relevant distinction to reflect differences in productivity and actual forest practices, but are defined for both even-aged and uneven-aged systems. Management prescriptions included in the model are detailed in Table 2. Landowner objectives and intensity of management are modeled as low, medium or high intensity.

Table 2. Management Prescriptions used in RMTS and RMTSET.

Existing Stands	
Grow Only (Even-aged)	Grow only. Regeneration harvest at maximum contribution to objective function.
Commercial Thin (Even-aged)	Thin when stand volume is >20 mbf/acre. Remove 30% of the volume. Regeneration harvest at maximum contribution to objective function.
Partial Cut 1 (Uneven-aged)	Cut when stand volume is >35 mbf/acre. Remove 15% of volume. Repeat each time the volume criterion is met.
Partial Cut 2 (Uneven-aged)	Cut when stand volume is >15 mbf/acre. Remove 33% of volume. Repeat each time the volume criterion is met.
Partial Cut 3 (Uneven-aged)	Cut when stand volume is >30 mbf/acre. Remove 50% of volume. Repeat each time the volume criterion is met.
New stands: all are even-aged management	
Plant only	Plant and grow only. Regeneration harvest as above.
Plant and Commercial Thin	Plant and commercial thin/final harvest as above.
Natural regeneration only	Naturally regenerate and grow only. Harvest at maximum contribution to objective function.
Natural and Commercial Thin	Naturally regenerate and commercial thin/final harvest as above.

RMTS models existing even-aged stands and new (regenerated) even-aged stands separately. Acres of existing stands at time *t* have a yield table associated with them, indicating the volume available at harvest in any time period in the future. RMTS chooses the harvest timing for each acre for every existing stand by selecting the timing that contributes the most to consumer and producer surplus. Once harvested, each acre is considered a new stand, with a new management prescription for the region and forest type to be chosen in order to maximize the objective function. This formulation reduces dramatically the number of activities the model must consider when optimizing, yet retains essential location information (because plot location is incorporated into inventory unit information). Acres of uneven-aged stands are assigned the management schedule, including repeated harvest timing and harvested volumes, that contributes the most to the objective function over the planning horizon. Prescriptions designed to reduce wildfire risk or restore forest health on public lands can operate similar to uneven-aged management schedules.

Current milling capacity requires a per-unit maintenance investment in each period and depreciates at a set rate. New investment in milling capacity occurs at current mill sites. Conversely, should the supply of timber fail to meet a required capacity utilization level, the mill shuts down (stops receiving logs) and standing capital continues to depreciate. This quasi-fixed, endogenous treatment of investment is unique in the RMTS as compared with other timber market models and essential for ultimately incorporating new, emerging biomass technologies into the market model. RMTS models the supply of logs delivered to both sawmills and plywood/veneer mills, as both of these technologies use round wood as primary inputs. Although the treatment of capacity adjustment is the same for the two types of mills within the model, the elasticities of demand for logs that drive mill-level demand are estimated separately for plywood/veneer mills and sawmills.

Current stand conditions are based on Forest Inventory and Analysis (FIA) data and projections of future inventory and harvestable material are developed with the forest growth simulation model Forest Vegetation Simulator (FVS). The data and programs are discussed further in chapter 4, model inputs. Of relevance to this chapter is that both the FIA data and FVS provide information at the tree level for current and future stand conditions. Within RMTS, the volume harvested per acre is computed using the sum of the individual tree volume components, estimated within FVS using allometric equations and the measured tree characteristics from FIA. The volume of the bole of the tree from a one foot stump up to a six-inch diameter top, minus a set percentage allocated to defect and breakage, is designated as sawtimber and is eligible to be harvested from the known plot location and shipped to mills with known locations. In this way landowners trade off destinations of the material in order to maximize their revenues, while mills trade off sources of logs to minimize their costs.

The volume between the six-inch diameter top and a four-inch diameter top is designated as pulpwood and is modeled as chipped on the landing or at a remote location and sent to known pulp mill locations for an exogenously determined price based on current market prices in the region. All other material, including limbs and the top of the tree, is currently left at the harvest site. All even-aged acres have associated site prep and planting costs immediately following harvest, reflecting the current forest practice laws regarding replanting.

Public land harvest is determined separately from profit-maximizing private harvest behavior. Public land harvest levels are policy decisions that operate outside the incentives of the forest products market. Since these decisions are made exogenously to the market, public land harvest in the base scenario is set at a level that is a continuation of recent levels of harvest by county. Specific acres within each county chosen for harvest in order to fulfill the quota are chosen within RMTS in a cost-minimizing manner. This is a plausible scenario as federal forest managers with limited budgets would likely choose the cheapest stands to harvest in order to minimize the cost of producing the allowable cut.

The use of both FIA and FVS data allows for public lands harvest assumptions to be relaxed in order to explore policy scenarios. For example, harvest increases that result from fuel treatments across the landscape can be modeled along with the effects of these public harvests on the overall forest products market. This connection is essential to modeling outcomes of policy changes. Large increases in supply of material from public lands affect market prices and, in turn, the level of supply offered from private lands. RMTS models this interaction and thus can be used to realistically portray the effect of public lands policy changes on the forest products market, including the amount and ownership of material flowing from particular forest plots of all ownerships to individual mills.

3.5 RMTS Model Description

Let X_{nj} be the number of acres of forest inventory unit *n* assigned to management prescription *j*[4]. Let I_{mt} be the units of capacity-increasing investment purchased at mill *m* in time *t*. The superscript *s* denotes the flow of material destined for sawn materials (logs for lumber or veneer/plywood). RMTS chooses the two control variables:

$$X_{nj} \, \forall \, n = 1, \ldots, N \; and \; j = 0, \ldots, J$$

$$I_{mt} \; \forall \, m = 1, \ldots, M \; and \; t = 0, \ldots, T-1$$

in order to maximize the sum of discounted producer and consumer surplus from the processing of logs *s* into lumber or plywood/veneer at mills *m* and the discounted value of the forest resource in the region in perpetuity:

$$\max_{X_{nj,}I_{mt}} \sum_{t=0}^{T-1} \left[\left(\frac{\sum_{m=1}^{M} \left(\int_{q=0}^{Q_{mt}^{S}} P_t^s \,(q, K_{mt}) dq - kK_{mt} - uI_{mt} - \sum_{n=1}^{N} \sum_{j=1}^{J} \left(w_{nt} X_{njmt} D_{nm}^{s} \right) \right)}{(1+r)^t} \right) - \left(\frac{\sum_{n=1}^{N} \sum_{j=1}^{J} X_{nj} C_{nt}}{(1+r)^t} \right) \right] + \frac{(P_T^S(q, K_T) Q_T^S - C_T^S Q_T^S)}{r(1+r)^T} \tag{18.1}$$

subject to:

$$Q_t^s = \sum_{m=1}^{M} Q_{mt}^s = \sum_{n=1}^{N} \sum_{j=1}^{J} w_{nt} X_{njmt} + EXOG_t^s - EXP_t^s \; \forall \, t \tag{19}$$

$$K_{mt+1} = K_{mt}(1 - \delta) + I_{mt} \; \forall \, m, t \tag{20}$$

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[4] X_{nj} adds to the objective function only in periods when treatments or harvests occurs. As discussed above, uneven-aged stands and public lands follow one management regime throughout the projection period, with predetermined harvest times. Even-aged stands are harvested in the time period that maximizes contribution to the objective function.

$$Q_{mt}^{s} \le K_{mt} \quad \forall m, t \tag{21}$$

$$Q_{mt}^{s} \ge \mu K_{mt};\ otherwise\ 0 \quad \forall\, m, t \tag{22}$$

$$\sum_{m=1}^{M} X_{njmt} w_{nt} = X_{nj} w_{nt} \quad \forall\, n, j, t \tag{23}$$

$$\sum_{n=1}^{N} \sum_{j=1}^{J} X_{nj} = G \tag{24}$$

where:

Q_{mt}^{s}	is the total volume of logs *s* delivered to mill *m* in time *t*
Q_{t}^{s}	is the total supply of logs *s* delivered to all mills in time *t*
$P_{t}^{s}(q, K_{mt})$	is the per-volume price for logs *s* in time *t*
X_{nj}	are the acres of inventory unit *n* assigned to management prescription *j*
X_{njmt}	are the acres from inventory unit *n* assigned to management prescription *j* with material travelling to mill *m* in time *t*
w_{nt}	is the per-acre log volume harvested from inventory unit *n* in time *t*
C_{nt}	is the per-acre cost for management (silviculture, harvest cost) from inventory unit *n* in time *t*
D_{nm}^{s}	is the per-volume cost for transport of logs *s* from inventory unit *n* to mill *m*
k	is the per unit cost of maintaining capital stock at mills
K_{mt}	are the units of existing capital stock in time *t* (maximum processing capacity) for mill *m*
u	is the per-unit cost of purchasing new capital stock for mills
I_{mt}	are the units of new capital stock (capacity expansion) for mill *m* purchased in time *t*

Q_T^s	is the annual average volume of logs delivered to mills, post-projection
c_T	is the annual average cost for log harvest and transport, post-projection
r	is the real discount rate
$EXOG_t^s$	is the exogenous (price-invariant) additional log supply in time *t*
EXP_t^s	is the net export of logs in time *t*
δ	is the depreciation rate of capital stock
μ	is the minimum capital stock utilization rate, and
G	is the total area of forest.

The objective function (eq. 18.1) maximizes, over the control variables described above, consumer and producer surplus. The integral in the first term of the first parenthesis calculates the gross benefit to consumers (mills) of the quantity of stumpage consumed (the area under the demand curve for logs up to the amount consumed). The second two terms deduct the cost of maintaining and increasing capacity in sawmills. The final term, along with the next parenthetical term, sums the costs, including management, harvest, site preparation after harvest, and transportation costs, of producing and delivering the logs consumed. The final term of the objective function calculates the present benefit of log harvest at a level determined by an application of Von Mantel's formula, where the level of even-flow harvest in perpetuity from a regulated forest is calculated within the model as being equal to two times the terminal inventory divided by the typical rotation age from the model solution (Bettinger et al. 2010)

Equations (19) through (24) are the active constraints for this model formulation. Equation (19) ensures that the quantity of logs consumed in any time period does not exceed the amount harvested in that period. Exogenous sources of supply (public lands harvest) and exports to other regions are accounted for in this constraint.

Equations (20) through (22) are capacity controls. Equation (20) calculates next period's facility-level capacity as a function of this period's depreciation and the endogenous investment decision in sawmills. Without any endogenous investment, capacity will depreciate steadily over time. Equation (21) ensures that receipts of raw materials at sawmills does not exceed current capacity constraints in any time period. Equation (22) forces the idle choice should delivered logs drop below a minimum capacity utilization amount at any given mill.

Equation (23) and (24) are harvest balance and area controls. The first constraint requires that all material delivered from acres X_{nj} to all mills in any period equal the total amount harvested in every inventory unit and management regime, while the second requires all manageable land to be allocated to a management regime or be available for potential harvest (reserved land, such as public lands in wilderness, are not considered part of the original land base).

3.6 RMTSET Model Description (Bio-refinery Model)

RMTSET builds on RMTS by tracking an additional source of supply (chips from branches and tops or small-diameter, non-merchantable trees chipped and used for biomass) and a new source of demand (production of jet fuel). Within the NARA project, RMTSET is used to help assess the feasibility of locating a plant in the northwest that would turn forest biomass into isobutanol, an input in the production of jet fuel. Additional supply material (woody biomass for chips not currently modeled as destined for the pulpwood market, both clean and dirty[5]) are tracked through the market, along with traditional harvest material (logs for lumber, veneer, or plywood manufacturing). The additional supply of both products that may result from treatments to improve forest health and reduce wildfire risk can be modeled from private and public lands. The effects of this demand on the forest products market can be assessed with changes in log price and quantity demanded at traditional mills in the region, and in the locations and levels of harvest on private land. For NARA, a regional supply curve of biomass is generated through this model. As described previously, logs up to a 6” top are designated for sawlog use; tops between 4” and 6” along with a breakage allocation are considered pulp material; and tops above 4”, along with branches and a portion of breakage, are considered the biomass supply. The estimated biomass on site is not considered fully recoverable, however. Proportions of the biomass pool are excluded due to likely physical degradation in logging or the scattered nature of the material on the site. RMTSET allows for some competition between products, such as the use of designated pulpwood as biomass chips, by allowing for products initially targeted for a particular use to be re-allocated (downgraded) to another use based on current prices.

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[5] “Clean” and “dirty” chips refer to different source material. Clean chips are from the debarked stem of the tree; this high-quality chip material is currently used in paper production as well as in engineered materials. Dirty chips are whole-tree or lower value residue chips. They may contain material from bark, branches, or needles as well as some stem material. This is a lower-quality product typically used for direct biomass energy production (for example, in co-generating heat or power at a mill), when used at all. The source material tracked within RMTSET destined for a bio-refinery is defined as a product with minimum bark standards (< 10%) and is intermediate in quality between traditional “clean” and “dirty” definitions.

This model introduces the superscript *b* to track the flow of biomass material. In this formulation, all biomass material is destined to be converted to bio-isobutanol at a large, central processing facility (denoted as facility *a*), and the biomass is transported directly from the harvest site (inventory unit *n*) to the plant *a* that converts the chips into liquid that will be further refined into jet fuel. This material is further designated with the superscript LOW to differentiate its price from an additional biomass supply stream that occurs in other versions of the model. In this case, the designation LOW represents material that has not been altered from its state once it has been chipped in the woods. The material is of relatively low value, and low market price. It is also costly to transport, as it is bulky and/or of high moisture content.

RMTS has been used at the regional level (e.g. eastern or western Oregon) with flows between regions modeled as exports. The NARA project is incorporating the potential for biomass use from portions of a four-state region (Oregon, Washington, Idaho and Montana). For this, RMTSET has been developed with data and parameters for the Missoula Corridor, a region encompassing northwest Montana, northern Idaho, and northeastern Washington, along with the Mid-Cascades to Pacific region (Western Oregon and Western Washington).

As before, let X_{nj} be the number of acres of forest inventory unit *n* assigned to management prescription j. Let I_{mt} be the units of capacity-increasing investment purchased at mill *m* in time *t*. RMTSET chooses the control variables:

$$X_{nj} \,\forall\, n = 1, \dots, N \text{ } and \text{ } j = 0, \dots, J$$

$$I_{mt} \,\forall\, m = 1, \dots, M \text{ } and \text{ } t = 0, \dots, T-1$$

in order to maximize the sum of discounted producer and consumer surplus from the processing of logs *s* into lumber/plywood/veneer at mills *m*, the use of biomass *b* at a large-scale jet fuel production plant *a*, and the discounted future value of the forest resource in the region:

$$\max_{X_{nj},I_{mt}} \sum_{t=0}^{T-1} \left[\left(\frac{\sum_{m=1}^{M} \left(\int_{q=0}^{Q_{mt}^{s}} P_t^s\,(q, K_{mt}) dq - kK_{mt} - uI_{mt} - \sum_{n=1}^{N} \sum_{j=1}^{J} \left(w_{nt} X_{njmt} D_{nm}^{s} \right) \right)}{(1+r)^t} \right) - \left(\frac{\sum_{n=1}^{N} \sum_{j=1}^{J} X_{nj} C_{nt}}{(1+r)^t} \right) + \left(\frac{P_t^{b,LOW} Q_{at}^{b} - \sum_{n=1}^{N} \sum_{j=1}^{J} \left(y_{nt} X_{nj} D_{na}^{b} \right)}{(1+r)^t} \right) \right] + \frac{(P_T^s(q, K_T) Q_T^s - C_T^s Q_T^s) + (Q_T^b P_T^b - C_T^b Q_T^b)}{r(1+r)^T} \tag{18.2}$$

subject to:

$$Q_t^s = \sum_{m=1}^{M} Q_{mt}^s = \sum_{n=1}^{N} \sum_{j=1}^{J} w_{nt} X_{njmt} + EXOG_t^s - EXP_t^s \;\forall\, t \tag{19}$$

$$K_{mt+1} = K_{mt}(1 - \delta) + I_{mt} \;\; \forall\, m, t \tag{20}$$

$$Q_{mt}^s \le K_{mt} \quad \forall m, t \tag{21}$$

$$Q_{mt}^s \ge \mu K_{mt};\ otherwise\ 0 \;\; \forall\, m, t \tag{22}$$

$$\sum_{m=1}^{M} X_{njmt} w_{nt} = X_{nj} w_{nt} \;\; \forall\, n, j, t \tag{23}$$

$$\sum_{n=1}^{N} \sum_{j=1}^{J} X_{nj} = G \tag{24}$$

$$Minimum_a \le Q_{at}^b \le Capacity_a \tag{25}$$

$$Q_{at}^b = \sum_{n=1}^{N} \sum_{j=1}^{J} y_{nt} X_{nj} \tag{26}$$

where:

Q_{mt}^s	is the total volume of logs *s* delivered to mill *m* in time *t*
Q_t^s	is the aggregate supply of logs *s* delivered to all mills in time *t*
$P_t^s(q, K_{mt})$	is the per-volume price for logs *s* in time *t*

X_{nj}	are the acres of inventory unit *n* assigned to management prescription *j*
X_{njmt}	are the acres from inventory unit *n* assigned to management prescription *j* with material travelling to mill *m* in time *t*
w_{nt}	is the per-acre log volume harvested from inventory unit *n* in time *t*
C_{nt}	is the per-acre cost for management (silviculture, harvest cost) from inventory unit *n* in time *t*
D_{nm}^{s}, D_{na}^{b}	is the per-acre cost for transport of sawlogs *s* or biomass *b* from inventory unit *n* to mill *m* or isobutanol plant *a*, respectively
k	is the per unit cost of maintaining capital stock at mills
K_{mt}	are the units of existing capital stock in time *t* (maximum processing capacity) for mill *m*
u	is the per-unit cost of purchasing new capital stock for mills
I_{mt}	are the units of new capital stock (capacity expansion) for mill *m* purchased in time *t*
$P_{t}^{b,LOW}$	is the price of biomass *b* in time *t*; price offered is *LOW* for unprocessed material
Q_{at}^{b}	is the total volume of biomass *b* delivered to isobutanol plant *a* in time *t*
Q_{T}^{s}, Q_{T}^{b}	is the annual average volume of logs and biomass utilized, respectively, post-projection
C_{T}^{s}, C_{T}^{b}	is the annual average cost for logs *s* and biomass *b* harvest and transport, post-projection
r	is the real discount rate

$EXOG_t^s$	is the exogenous (price-invariant) additional log supply in time *t*
EXP_t^s	are the net exports of logs in time *t*
δ	is the depreciation rate of capital stock
μ	is the minimum capital stock utilization rate
G	is the total area of forest
y_{nt}	is the per-acre biomass volume harvested from inventory unit *n* in time *t*.

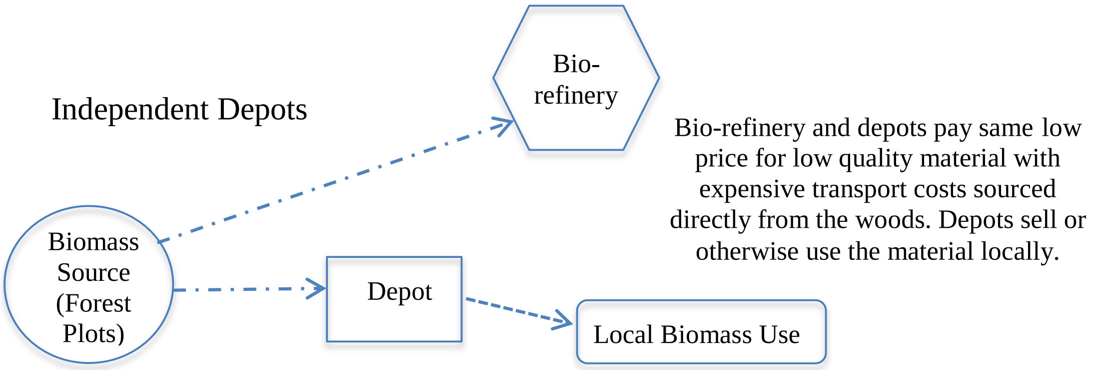
The objective function (18.2) maximizes, over the control variables described above, consumer and producer surplus. Equation (18.2) differs from (18.1), the objective function for RMTS, in the inclusion of the third parenthetical term. The new term calculates the net surplus achieved by moving biomass material from the woods directly to a large-scale processing plant as the quantity delivered times the exogenously determined price minus the transport and collection costs. Equations (19) through (24) are constraints defined as in section 3.5. The new constraints, equations (25) and (26), ensure that the quantity of biomass consumed in any time period does not exceed the amount harvested in that period, and that the quantity of delivered biomass at the large-scale production facility is at least the minimum required, but does not exceed capacity. As there is likely to be little trade across regions in biomass, all harvested biomass material is accounted for in the deliveries to refineries. By not including a minimum capacity utilization constraint, the assumption is that the production of isobutanol for fuel is scalable up to the plant capacity; the plant can scale down production to any level above a minimum one without being required to idle. Currently, the model can determine available biomass to multiple hypothetical plant sites. Hypothetical plant locations, as previously discussed, are determined within the NARA project by other teams, but can include any location established within the model. The delivery of biomass to any given location is optimized with respect to maximizing consumer and producer surplus, but the location of the plant in space is not optimized.

3.7 RMTSET with Extensions Model Description (Depot Model)

The vision embodied by the NARA project for the use of woody biomass material carries with it significant potential benefits: marketable use of previously unmerchantible material, the possible job increases in areas where harvest will occur, greater energy independence for the nation as a whole, and the large capital investment and jobs produced by the plant itself. Due to the infrastructure and transportation linkages necessary for a large-scale facility, the most likely locations for development are urban areas with relatively diversified economies. Yet there may be the potential for greater benefits for rural communities by establishing intermediate processing facilities that can take the raw material and increase its value, reduce its transport cost, and provide value-capturing manufacturing employment while also providing inexpensive biomass for local use. Emerging technologies can take advantage of idle capacity in rural areas by pre-processing biomass from the woods into more uniform, higher quality material that is then delivered to a final fuel production plant. As new centers of processing, rural communities could benefit both from the increased nearby harvesting jobs and direct employment in the intermediate processing facilities. In addition, they could benefit from the supply of raw chips coming into the local market by utilizing some of the raw, lower quality material for local, small-scale use (e.g. institutional boilers that provide heat for schools or hospitals).

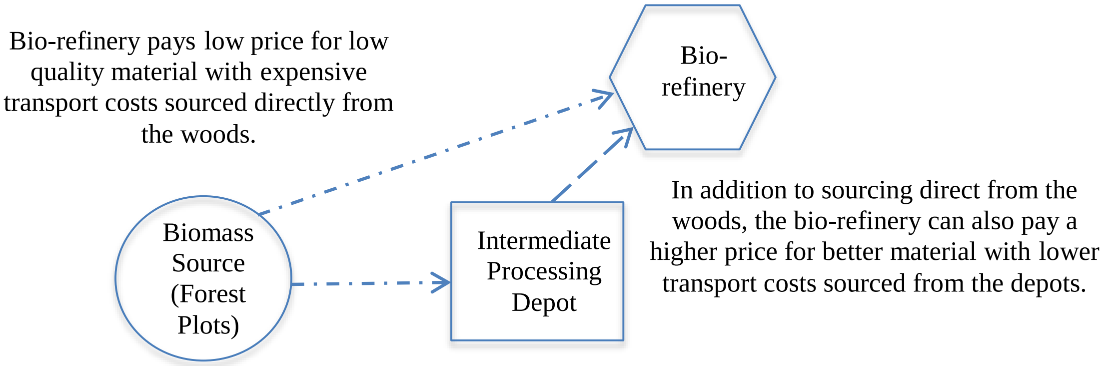
Modifying RMTSET to incorporate intermediate processing depots and local use of biomass allows the analysis of two of the research questions posed in section 1.4, and to assess the potential for biomass to contribute to overall rural development goals. The potential paths of biomass use modeled in RMTSET and RMTSET with extensions are outlined in Figure 7. In RMTSET, the model estimates the quantity delivered to a final bio-refinery for a given price of chips, displayed as the solid line path from woods to bio-refinery. The material is as described previously: of low value and of relatively high moisture content (more costly to transport). To compare the potential benefits of pre-processing or transshipments in rural communities, RMTSET with extensions is run for two separate cases: independent and dependent depots.

Independent Depots



Bio-refinery and depots pay same low price for low quality material with expensive transport costs sourced directly from the woods. Depots sell or otherwise use the material locally.

Dependent Depots



Bio-refinery pays low price for low quality material with expensive transport costs sourced directly from the woods.

In addition to sourcing direct from the woods, the bio-refinery can also pay a higher price for better material with lower transport costs sourced from the depots.

Figure 7. Biomass flows with independent and dependent depots.

The independent depot scenario models biomass use across the landscape, whether by a bio-refinery or a small scale depot. Harvest residues flow from the woods to either depot or bio-refinery, but not in between the two. Biomass at the depots is assumed to be used for local purposes, such as institutional heating or boiler systems, while biomass travelling to the bio-refinery is assumed to be converted into a more highly refined product. All destinations pay the same price for delivered biomass and function independently of each other. Differences in demand between the depots and the bio-refinery are related to the establishment and operating costs modeled for the depots and the spatial location of each, relative to the supply source of harvest residues (the forest being harvested).

The dependent depot scenario models a use of depots as collection and pre-processing centers in service to a bio-refinery. Biomass travels from the harvest site to a rural depot for some pre-processing (examples of potential pre-processing include densification through drying and/or the screening of the material to create a more even and consistent product) and transshipment into more efficient vehicles, and then moves to a bio-refinery. In this latter case, the depots exist to refine the product and to lower the cost of the procurement of the necessary amount of biomass at the bio-refinery, not for local use (dependent depots). The demand at depot locations is now by necessity more tied to the spatial location of the bio-refinery, because the material is moving exclusively from the depot to the bio-refinery. In the dependent depot scenario, the bio-refinery can purchase material directly from the woods for the same price as the depots pay, or can purchase the processed material from the depots for a higher price. Depots located in between the harvest sites and the bio-refinery also result in transport savings for a part of the transport distance.

These local processing facilities are modeled through investment-driven changes in regional biomass processing capacity, which is currently assumed to be zero for this quality type of biomass product[6]. Intermediate processing plants exist as a fixed-cost investment choice of varying capacity levels for the model to select in locations with existing infrastructure (e.g. a labor force, transportation corridor access) and nearby biomass potential. Depots also incur operating costs per unit of material that passes into the facility. Potential sites for development – investment primordia – were preselected based on current community conditions along both social and economic facets. The operation of processing facilities can be tracked over the projection period.

The optimal investment in these technologies depends on their marginal contribution to consumer and producer surplus. Additional weighting of the rural development benefits of intermediate processing facilities can be incorporated into RMTSET with extensions by including a constraint that specifies a minimum level of community benefits that must be met as part of the solution. Preference can be given to

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[6] Although there is biomass use for heat and power in the regions, this primarily occurs as co-generation at existing mills, using milling residue. By assuming that the current processing capacity is zero, the model assumes no change in current use and current supplies of biomass, allowing for prediction of changes in both supply and demand for biomass resulting from new markets, relative to current conditions.

different types of communities (e.g., those with high levels of existing business capacity, or those historically highly reliant on the forest products industry) by adjusting the values associated with investment in these places. Key output from RMTSET with extensions is the locations selected for investment in depot capacity.

Let X_{nj} be the number of acres of forest inventory unit *n* assigned to management prescription *j*. Let I_{mt} be the units of capacity-increasing investment purchased at mill *m* in time *t*. Let F_{zt} be the units of intermediate biomass processing investment (start-up capacity) purchased at sites *z* in time *t*. RMTSET with extensions chooses the control variables:

$$X_{nj} \,\forall\, n = 1, \ldots, N \; and \; j = 0, \ldots, J$$

$$I_{mt} \;\forall\, m = 1, \ldots, M \; and \; t = 0, \ldots, T-1$$

$$F_{zt} \;\forall\, z = 1, \ldots, Z \; and \; t = 0, \ldots, T-1$$

in order to maximize the sum of discounted producer and consumer surplus from the processing of logs *s* into lumber/plywood/veneer at mills *m*, the discounted returns from the processing of biomass *b* at intermediate processing facilities *z*, the discounted return from the purchase of biomass *b* at a large-scale jet fuel production plant *a*, and the discounted future value of the forest resource in the region:

$$\max_{X_{nj}, I_{mt}, F_{zt}} \; \sum_{t=0}^{T-1} \left[\left(\frac{\sum_{m=1}^{M} \left(\int_{q=0}^{Q_{mt}^{S}} P_t^S \, (q, K_{mt}) dq - kK_{mt} - uI_{mt} - \sum_{n=1}^{N} \sum_{j=1}^{J} \left(w_{nt} X_{njmt} D_{nm}^{S} \right) \right)}{(1+r)^t} \right) - \right.$$

$$\left(\frac{\sum_{n=1}^{N} \sum_{j=1}^{J} X_{nj} C_{nt}}{(1+r)^t} \right) +$$

$$\left(\frac{\sum_{z=1}^{Z}\left(\theta P_t^{b,LOW} Q_{zt}^b+(1-\theta)P_t^{b,HIGH} Q_{zat}^b-hQ_{zt}^b-lF_{zt}-\sum_{n=1}^{N}\sum_{j=1}^{J}\left(y_{nt}x_{nj}D_{nz}^b\right)-(1-\theta)v_{az}Q_{zat}^b\right)}{(1+r)^t}\right)+$$

$$\left(\frac{P_t^{b,LOW} Q_{at}^b-\sum_{n=1}^{N}\sum_{j=1}^{J}\left(y_{nt}X_{nj}D_{na}^b\right)}{(1+r)^t}\right)\Bigg] + \frac{(P_T^S(q,K_T)Q_T^S-C_T^S Q_T^S)+(Q_T^b P_T^b - C_T^b Q_T^b)}{r(1+r)^T} \tag{18.3}$$

subject to:

$$Q_t^s = \sum_{m=1}^{M} Q_{mt}^s = \sum_{n=1}^{N}\sum_{j=1}^{J} w_{nt}X_{njmt} + EXOG_t^s - EXP_t^s \;\forall\, t \tag{19}$$

$$K_{mt+1} = K_{mt}(1-\delta) + I_{mt} \;\;\forall\, m,t \tag{20}$$

$$Q_{mt}^s \le K_{mt} \quad \forall m,t \tag{21}$$

$$Q_{mt}^s \ge \mu K_{mt};\ otherwise\ 0 \;\;\forall\, m,t \tag{22}$$

$$\sum_{m=1}^{M} X_{njmt}w_{nt} = X_{nj}w_{nt} \;\;\forall\, n,j,t \tag{23}$$

$$\sum_{n=1}^{N}\sum_{j=1}^{J} X_{nj} = G \tag{24}$$

$$Minimum_a \le Q_{at}^b \le Capacity_a \tag{25}$$

$$Q_t^b = Q_{at}^b + \sum_{z=1}^{Z} Q_{zt}^b = \sum_{n=1}^{N}\sum_{j=1}^{J} y_{nt}X_{njt} \tag{27}$$

$$Q_{zat}^b = \sum_{z=1}^{Z} Q_{zt}^b\ IFF\ \theta = 0 \tag{28}$$

$$H_{zt+1} = H_{zt} + F_{zt} \;\;\forall t \tag{29}$$

$$Q_{zt}^b \le H_{zt} \quad \forall z,t \tag{30}$$

where:

Q_{mt}^s	is the total volume of logs *s* delivered to mill *m* in time *t*
Q_t^s	is the aggregate supply of logs *s* delivered in time *t*
$P_t^s(q, K_{mt})$	is the per-volume price for logs *s* in time *t*
X_{nj}	are the acres of inventory unit *n* assigned to management prescription *j*

X_{njmt}	are the acres of inventory unit *n* assigned to management prescription *j* with material traveling to mill *m* in time *t*
w_{nt}	is the per-acre log volume harvested from inventory unit *n* in time *t*
C_{nt}	is the per-acre cost for management (silviculture, harvest cost) from inventory unit *n* in time *t*
D_{nm}^{s}	is the per-acre cost for transport of sawlogs *s* from inventory unit *n* to mill *m*
k	is the per unit cost of maintaining capital stock at mills
K_{mt}	are the units of existing capital stock in time *t* (maximum processing capacity) for mill *m*
u	is the per-unit cost of purchasing new capital stock for mills
I_{mt}	are the units of new capital stock (capacity expansion) for mill *m* purchased in time *t*
θ	is a [0,1] variable set to 1 in the independent depot case and 0 in the dependent depot case
$P_{t}^{b,LOW}$	is the price of biomass *b* in time *t*; price is *LOW* for unprocessed material
Q_{zt}^{b}	is the total volume of biomass *b* delivered to depot *z* in time *t*
Q_{t}^{b}	is the total volume of biomass *b* delivered in time *t*
$P_{t}^{b,HIGH}$	is the price of biomass *b* in time *t*; price is *HIGH* for processed material
Q_{zat}^{b}	is the total volume of processed biomass *b* delivered from depot *z* to refinery *a* in time *t*
h	is the per-unit cost of operating/processing biomass at facility *z*

l	is the per-unit cost of establishing facility *z*
F_{zt}	is the number of units of investment in new intermediate processing facilities *z* added in time *t*
y_{nt}	is the per-acre biomass volume harvested from inventory unit *n* in time *t*
D_{nz}^{b}	is the per-acre cost for transport of biomass *b* from inventory unit *n* to depot *z*
v_{az}	is the per-unit transportation cost of processed biomass from facility *z* to plant *a*
Q_{at}^{b}	is the total volume of biomass *b* delivered to plant *a* in time *t*
D_{na}^{b}	is the per-acre cost for transport of biomass *b* from inventory unit *n* to isobutanol plant *a*
Q_T^s, Q_T^b	is the annual average volume of logs and biomass utilized, respectively, post-projection period
C_T^s, C_T^b	is the annual average cost for log *s* and biomass *b* harvest and transport, post-projection period
r	is the real discount rate
$EXOG_t^s$	is the exogenous (price-invariant) additional log supply in time *t*
EXP_t^s	are the net exports of logs in time *t*
δ	is the depreciation rate of capital stock
μ	is the minimum capital stock utilization rate, and
G	is the total area of forest.

The objective function (18.3) maximizes, over the control variables described above, consumer and producer surplus. Equation (18.3) differs from the previous objective functions in the inclusion of the third parenthetical term. This term is unique to RMTSET with extensions and calculates the net benefit of intermediate processing of biomass at depots. The theta term differentiates the dependent depot case ($\theta = 0$) from the independent depot case ($\theta = 1$). It includes the total price paid for the biomass material (a higher price in the dependent depots case) minus the costs to open and operate the depots and the cost to transport both the raw material from the woods to the depot as well as the lower cost to transport the refined material from the depot to the refinery (in the dependent depot scenario). As before, the final two terms calculate net surplus achieved by moving biomass material from the woods directly to a large-scale processing plant and the present value of log harvest and biomass use in perpetuity.

Equations (19) through (25) are constraints defined as in section 3.6. New constraints are found in equations (27) through (29). Equation (27) replaces equation (26) from section 3.6, and sets total biomass quantity limits while allocating all biomass removed as delivered to either a refinery or a depot. Equation (28) requires, for the dependent depot case, all material arriving at a depot to be transferred to the bio-refinery. Equation (29) calculates next period’s facility-level capacity as a function of this period’s capacity and changes in capacity selected for the intermediate processing facilities. Each facility can move up or down capacity steps in any period, although the cost of establishment is calculated only with increases or positive steps in capacity (the treatment of depot capacity is further explained in section 5.5). Unlike the mill capacity formulation, the depots do not depreciate with time in this formulation. Equation (30) ensures that receipts of raw materials at depots does not exceed current capacity constraints.

4. Model Inputs and Details

4.1 Introduction

Information and input data needed for modeling scenarios within RMTS include: estimated regional sawmill and plywood/veneer mill demand functions for wood fiber; regional estimates of current and future inventory under all modeled management regimes; potential yields of harvested timber and biomass (supply) in each period; harvest and transport costs for sawlogs and biomass from the woods to the mills/processing sites; management costs under different management regimes; and estimated levels of investment required in each time period to maintain existing mill capacity. Additional data required for RMTSET and RMTSET with extensions includes the investment cost and maintenance cost required to establish intermediate processing facilities and the potential sites for intermediate processing facilities. Some of this information was generated as a part of the NARA project and will follow previous methodologies, while some information is newly generated for use with RMTSET.

This chapter describes the majority of the input data required and its development (where applicable), in particular the estimation of lumber and plywood industry elasticities of demand for logs that, in conjunction with levels of harvest, determine the endogenous log price in each period in the model. Section 4.2 details the forest inventory input data and growth modeling procedure used to project volume available for harvest into the future. Silvicultural prescriptions and other management issues are discussed in section 4.3, and other data inputs in section 4.4. The remaining sections describe the mill-level data and information used and estimated as part of this project. Section 4.5 describes location and capacity information, while sections 4.6 through 4.9 describe the equation system, input data, estimation issues and methods, and results of the estimation of factor demand elasticities used in the dissertation model and in the NARA project. All information on the intermediate processing facilities, including specifications used and the selection criteria for potential locations, is covered in chapter 5.

4.2 Current and Future Forest Inventory

The harvest of logs to supply to the forest products market is a key determinant of both sawlog price and biomass availability. Since a large portion of the cost of getting logs to the market (mill) is transportation and thus is a function of the distance between forest and mill, both mill profitability and willingness to supply logs by landowners are dependent on the volume available at specific locations through time. A reliable and accurate spatial estimate of the current state of the forest resource across diverse landscape and ownerships, as well as the projected change in the resource over time, is essential in accurately modeling the forest products industry and management choices of landowners. For these purposes, RMTS/RMTSET relies on Forest Inventory and Analysis (FIA) data for current forest inventory and the Forest Vegetation Simulator (FVS) program for projections of future inventory. Both FIA data and the FVS program are produced, developed, and maintained within the research and development arm of the U.S.D.A. Forest Service.

FIA data is gathered on all forested lands, regardless of ownership, in a three phase process. In the first phase, remote sensing information is used to delineate forest land from non-forest land. In phase two, each plot, representing approximately 6,000 forested acres, is sampled for basic stand characteristics; further forest health measurements are collected on a subset of phase two plots in phase three.

RMTS/RMTSET relies on the tree-level information gathered in phase two. In western Oregon, FIA data is measured on 2,868 plots representing approximately 15,100,000 forested acres.

In the west, 10% of all plots in any one state are inventoried for phase two every year, resulting in a continuous, rolling observation of current standing inventory. Field crews revisit established plots and collect data on forest type, site attributes (e.g. slope, elevation), individual tree size (height and diameter) and species, and general individual tree condition. For each plot, ownership is also known, although precise location is not, for either data users or private landowners cooperating with the FIA program. Location information (latitude and longitude) for each plot is adjusted or "fuzzed" between one-half and one mile from the actual position, resulting in actual plot locations that are generally masked within a 500-acre area. Plot locations are altered both to protect landowner confidentiality and to discourage perverse incentives by landowners in management activities on measured locations; this way, plot data represents actual conditions on the landscape and landowner privacy is ensured while still allowing for spatially explicit information to be used and displayed.

Within any given FIA plot, the actual sampling protocol within phase two dictates that four sub-plots are measured at each plot location. Each sub-plot is assessed for its condition class, a discrete combination of landscape attributes, including ownership group, reserved land status, forest type, size class, and tree density. A single plot can have anywhere from one to four condition classes represented, and the expansion factors for plots with more than one condition class are adjusted downward from 6,000 acres accordingly. RMTS/RMTSET uses the condition class as the representative of forest stand, and within the model the control variable X_{nj} refers to the number of acres in inventory unit (condition class) n assigned to management prescription j (management prescriptions are described in section 4.3).

FVS is a family of forest growth simulation models, with 20 different variants of the model developed for specific geographic regions. It is an individual-tree, distance independent growth and yield model that can simulate inventories and yields for many silvicultural activities. Original design criteria for FVS included the ability to use existing inventory information as input and compatibility with FIA data. Five variants are required to model growth and yield within the C2P region: the Pacific Northwest Coast (PN) and Westside Cascades (WC) variants cover most of the forested area, along with small portions of area covered by the Southeast Alaska and Coastal British Columbia (AK), Klamath Mountains (NC), and Inland California and Southern Cascades (CA) variants.

The land base considered for management within RMTS/RMTSET does not include wilderness, roadless, or public areas otherwise excluded from management activities (these land classifications are indicated in the plot-level FIA data). The FIA data does not, however, contain any information about plot area in riparian zones. In Oregon, strict land use planning laws limit the change of the forested land base over time, and indeed there has not been a recent decline in forested area. It is possible that in the other states of the NARA region (or other states the model is applied to), the forest land base cannot be assumed to be constant over the projection period. In previous applications of RMTS, a decline in forest land base of 3.5% over a 15-year period was used for the state of Washington (Adams and Latta 2007).

4.3 Management and Silviculture Prescriptions

Supply of sawlogs within the model is estimated by projecting harvest choices and silvicultural actions for different landowners over time. The primary input into RMTS/RMTSET for supply consists of a per-acre yield table for each forest condition class and possible management regime combination (each potential X_{nj}) indicating the harvested amount, in thousand board feet (MBF), of sawlogs at different time periods, along with the concurrent production of biomass in green tons/acre. With over 5,000 condition classes and nine possible management choices for each, generation of all the possible yield tables becomes a major undertaking. As part of NARA, a streamlined version of FVS was developed at Oregon State University that allowed for easier processing of so many plot and management combinations.

Management regimes for private lands closely follow those used in previous applications of RMTS (Adams and Latta 2005; Latta and Adams 2005). Potential regimes for each inventory unit were initially developed with assistance from silviculturists and timber managers and reflect current even-aged and uneven-aged management practices on public and private lands. These regimes are detailed in Table 2 (section 3.4). In general, Westside forests of Oregon and Washington are managed with even-aged regimes in order to maximize profit. However, some owners may choose to utilize a partial cutting strategy (uneven-aged management).

For existing stands allocated to even-aged regimes, the yield tables indicate the amount of volume available in any period with clear-cut harvest (along with intermediate removal volumes if thinning regimes are selected); the age of final harvest is not specified. RMTS/RMTSET selects final harvest age based on each acre’s maximum contribution to consumer and producer surplus (subject to a minimum age constraint of 35 years for private landowners, 55 years for state, and 80 for federal lands). Following clear-cut harvest, acres become “new” stands with new yield tables and management options, including selecting the timing of final harvest. A mature stand in the beginning of the projection period could be harvested and become a “new” stand up to 3 times in a 100-year modeling horizon.

Existing stands can also be allocated to an uneven-aged regime. In this case, intermediate thinning treatments are assigned when stands reach desired conditions as defined by a volume (mbf/acre) criteria. Once assigned to an uneven-aged regime, that yield table is followed through the course of the projection. These stands do not enter a “new” pool as they are not regeneration harvested. Acres are allocated to a low, medium, or high intensity of uneven-aged management activities based on the maximum contribution to overall surplus.

Public supply is assumed to be non-responsive to price; fuel reduction treatments undertaken on public land to reduce wildfire risk have previously been modeled using percentages of maximum stand density index (or other biological cues) as targets. In this application, public supply is set exogenously as the average annual level of recent harvest from public lands in each county. Each county is then given an allowable cut target harvest and the model chooses which stands to apply towards the target. Since the model is seeking to maximize consumer and producer surplus, it will select the stands of minimum cost to meet the constraint. This is a reasonable depiction of how public agencies may choose to allocate harvest across a given area if they seek to meet an allowable cut at a minimum budget cost. Currently, no additional federal harvest actions (such as fuel reduction treatments) are modeled as that is not a concern on the west side of Oregon and Washington where the model is being applied. The potential exists, however, for exploration of other federal policies, e.g. harvest to encourage old-forest structures or general increases in the allowable cut on federal lands.

4.4 Management Cost Data

Logging and hauling costs are also critical input data. The yield tables for each particular stand type/management regime combination include specific harvest costs associated with moving material from the woods to roadside landings. Costs associated with harvest of sawlogs are well understood and estimated for each plot as the least-cost feasible harvest method, typically cable logging on steeper slopes and ground-based harvesting on flatter ground. Costs for in-woods biomass removal to the landing are estimated from current experience and were refined as a part of NARA. The model simulations presented in this dissertation assume \$17.50/bdt for biomass chipping and loading at the landing site and \$20/bdt for moving the biomass residue to the landing.

Within the model, the harvest occurs at the acre level, but the individual sample plot represents an approximately 6,000 acre area. In order to allow for the distribution of actual trees over that area, an average estimated yarding/skidding distance is applied to each acre to simulate the material moving to an assumed landing location and then to the nearest road. An additional matrix assigns transport costs, per MBF or BDT/mile, between each plot landing and each potential destination (existing mill for RMTS and existing mill and hypothetical bio-refinery or depot in RMTSET). The per-unit transport cost is added to the harvest cost for each selected harvest site/destination pair at the time of harvest. Other forest costs taken account of are the management cost associated with planting and site prep following regeneration harvest. Harvest cost information for Western Oregon was compiled using GIS as a part of the NARA project by Josh Clark of Oregon State University.

4.5 Mill Data

An essential component of RMTS and RMTSET is the current capacity in mills and processing centers, along with the elasticity of demand for sawlogs. Capacity information is necessary for both setting realistic maximum demand for sawlogs as well as determining the level of investment that may occur over the modeling horizon. Estimates of demand elasticity, in conjunction with current available supply (the modeled harvest amounts), determine the endogenous price for sawlogs within the model.

Current operating mill information was compiled by myself and others from several sources. A private company, Random Lengths, publishes an annual voluntary survey of the forest products industry in its annual “Big Book” (Random Lengths Annual). The USDA Forest Service also conducts or publishes periodic surveys of the industry (Gale et al. 2012; Spelter, Alderman, and McKeever 2007; Spelter, Alderman, and McKeever 2003). The difficulty lies in parsing out the accurate and relevant information from all these varying sources. Many do not list capacity information, or it is estimated in different units. Some include very small single-person mobile sawmills unlikely to affect the demand for sawlogs. Mills may still be considered active, yet have idled and be not currently processing timber. Information from all these sources was collected and compared with industry knowledge to determine the set of open mills to model. Overall regional capacity was computed by summing mill level estimates derived from the sources described above. As noted in the model description (chapter 3), constraints restrict a mill to operating within a range around that capacity, reflective of the reality that the quasi-fixed nature of capital in the short run limits the degree to which mills will increase or decrease processing.

4.6 Estimation Input Data

The profit function can be used to derive estimates of factor demands and supply as a function of input price (section 3.2). To derive the current elasticities of demand for sawlogs within the lumber and plywood/veneer industries, I follow the methodology used for the Canadian softwood industry (Latta and Adams 2000). Latta and Adams first estimate the industry profit function and the input and output factor demands, then compute the elasticity of demand. Profit functions and concurrent factor input demand functions were estimated econometrically using time series data of lumber output levels, labor and other variable input prices, stumpage prices, and industry capacity for sawmills and veneer/plywood mills separately, for each modeling region. The estimated elasticities of supply derived from these functions are a key input into RTMSET.

This section describes the data required for estimation, econometric issues in estimation, and the resulting estimates of elasticities. This methodology was used to estimate elasticities of demand for lumber and plywood/veneer industries in Montana, Idaho, Eastern Washington, and the Missoula Corridor (eastern Washington, Idaho, and Montana combined) and Cascades to Pacific (western Oregon and Washington combined) regions for use within the NARA project. The version of RMTSET in this dissertation utilized recent estimates of western Oregon lumber and plywood industries developed by Isabel Guerrero at Oregon State University (Guerrero 2012, unpublished Master's paper). Reported here are only the western Oregon results used in RMTSET, along with results from the western Washington lumber and plywood industries shown for illustration and comparison.

The equations presented in section 3.2 are an economic model of rational behavior for a profit maximizing firm. With a well-behaved profit function, well-behaved supply and demand derived equations can be recaptured (Chambers 1988). There are five important properties of a profit function: non-negativity, non-decreasing in output price, non-increasing in input prices, homogeneity of degree one in prices, and that the profit function is convex and continuous in output and input prices. As discussed above, given an indirect profit function (setting aside time subscripts and fixed capital) $\pi(w,p) = pq(w,p) - cS(w,p) - wL(w,p)$ where $q = q^*(w,p)$, Hotelling's Lemma provides the theoretical basis for capturing factor demand equations from the profit function:

$$\frac{\partial\pi(w,p)}{\partial p} = q^*(w,p) \tag{31}$$

$$\frac{\partial\pi(w,p)}{\partial c} = -S^*(w,p) \tag{32}$$

$$\frac{\partial\pi(w,p)}{\partial w} = -L^*(w,p) \tag{33}$$

Ensuring convexity requires checking the Hessian matrix H of second derivatives to confirm that it is symmetric and positive semi-definite, with non-negative eigenvalues:

$$H = \begin{bmatrix} \partial^2 \frac{\pi(w,p)}{\partial p^2} & \partial^2 \frac{\pi(w,p)}{\partial p \partial w} \\ \partial^2 \frac{\pi(w,p)}{\partial w \partial p} & \partial^2 \frac{\pi(w,p)}{\partial w^2} \end{bmatrix} \tag{34}$$

To estimate these relationships econometrically, I follow Latta and Adams (2000) and employ a quadratic functional form. The quadratic form is flexible, and should curvature properties (convexity) need to be imposed, they can be accommodated without loss of flexibility (Diewert and Wales 1987). Symmetry of coefficients is imposed *a* *priori*. The system is normalized by diving by the price of all other inputs (besides logs and labor), here measured by the all commodities producer price index (PPI)[7], and restricted (capital is quasi-fixed). Normalization ensures homogeneity of degree one. Estimations consider simultaneously the industry profit function along with two input factor demand equations (logs S and labor L) and an output supply function (the first derivatives of the profit function with respect to the output and input prices). The resulting system estimated separately for the lumber and plywood/veneer industry is:

$$\pi(p,w,k,t) = \alpha_0 + \beta_0 Y_p + \beta_1 S_p + \beta_2 L_p + 0.5\left[\beta_{00} Y_p^2 + \beta_{11} S_p^2 + \beta_{22} L_p^2\right] + \beta_{01} Y_p S_p + \beta_{02} Y_p L_p + \beta_{12} S_p L_p + \beta_{0k} Y_p K + \beta_{1k} S_p K + \beta_{2k} L_p K + \beta_{0t} Y_p t + \beta_{1t} S_p t + \beta_{2t} L_p t + \beta_k K + \beta_t t + \beta_{kt} K t + \beta_{kk} K^2 + \beta_{tt} t^2 \tag{35}$$

$$\frac{d\pi}{dY_p} = Y_q(p,w,K,t) = \beta_0 + \beta_{00} Y_p + \beta_{01} S_p + \beta_{02} L_p + \beta_{0k} K + \beta_{0t} t \tag{36}$$

$$\frac{d\pi}{dS_p} = -S_q(p,w,K,t) = \beta_1 + \beta_{01} Y_p + \beta_{11} S_p + \beta_{12} L_p + \beta_{1k} K + \beta_{1t} t \tag{37}$$

$$\frac{d\pi}{dL_p} = -L_q(p,w,K,t) = \beta_2 + \beta_{02} Y_p + \beta_{12} S_p + \beta_{22} L_p + \beta_{2k} K + \beta_{2t} t \tag{38}$$

where:

Y_q	is the output quantity of lumber or plywood
Y_p	is the output price of lumber or plywood, divided by the price of all other inputs

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[7] The producer price index is published by the United States Department of Labor, Bureau of Labor Statistics and measures the average change over time in the selling prices received by domestic producers for their output.

S_q is the sawlog quantity demanded as an input

S_p is the normalized sawlog price, divided by the price of all other inputs

L_q is the quantity of labor demanded as an input

L_p is the normalized labor price, divided by the price of all other inputs

K is capital stock in the industry, and

t is a time trend, representing technology.

Annual lumber and plywood/veneer output, lumber and plywood/veneer price, log quantity used, log price, labor quantity used, labor price, and industry capacity was gathered from 1970-2011 for all four states in the NARA region. Montana and Idaho information was available only at the state level; for Oregon and Washington, it was gathered at the half-state level (Westside and Eastside of each state). This data was used both as independent variables in the econometric estimation as well as to calculate annual profitability, the dependent variable in the first equation, for both the lumber and plywood/veneer industries.

Log recovery ratios (the rate at which board feet of raw logs are converted into board feet of finished lumber or square feet, 3/8” basis of plywood/veneer; these change over time with utilization standards and improved technology) and operating cost data were purchased from RISI, Inc., a for-profit company specializing in information about the forest products industry. Output of lumber and plywood/veneer was available through the Western Wood Products Association (WWPA) and log stumpage price from the Oregon Department of Forestry and LogLines, a subscriptions service provided by RISI. As noted above, capacity information was estimated from several USDA Forest Service studies of sawmills as well as opt-in annual directories of the forest products industry (Spelter and McKeever 1999; Spelter, McKeever, and Toth 2001; Spelter, Alderman, and McKeever 2003; Spelter, Alderman, and McKeever 2007; Random Lengths Annual).

The most problematic data to compile was that on labor quantity and costs. Each state is required to report employment and wages levels to the Bureau of Labor Statistics as part of the Quarterly Census of Employment and Wages program, but there are two main problems with this data. First, the change ca. 2000 from the Standard Industry Classification (SIC) system to the North American Industry Classification System (NAICS) has resulted in a large artificial decline in the reported number of employees in the forest products industry, most likely due to the separation of logging from the industry classification. There is no way to completely compare the two data sets at this time. Contacts at the state level were able to provide us with seamless data from 1991 – present for Idaho and from 1970 – 2002 for both regions of Oregon. Secondly, for some states, the small number of mills led to a severe disclosure issue for employment information for many of the years. For example, a special request of a leading plywood/veneer manufacturer in Montana enabled the state to proceed with releasing recent suppressed data for that industry, but there are few historical reports for the standard BLS classification systems for Montana that do not have serious data repression issues. In the end, data for Montana and Idaho on annual employment levels and average wages in sawmill and plywood/veneer industries were gathered from several sources at different industry levels in order to construct a time series of industry employment. In some cases, backcasting or averaging was required to fill in data gaps. Region-wide profit and factor demands are assumed to be the sum of all firm level profit and demands, allowing for a redistribution of demand back to the individual mill level based on mill-level current capacity estimates.

4.7 Estimation Issues and Methods

One issue with estimating this system is that the classic linear regression assumes stationarity of the data; otherwise, the results may be spurious. With stationary data, the mean and variance are constant over time. Time series data often, however, follow a trend or pattern over time, with each observation's value being highly correlated with the observation prior (P. Kennedy 1998). Although de-trending the data (such as estimating a model in first differences of variables rather than levels) is one solution, tests for stationarity are low power and frequently inconclusive, leading to some doubt as to whether or not differencing is necessary or accomplishes the goal in any particular case.

Estimating the model in levels when the data are stationary in first differences (underdifferencing) results in an error structure that is first order autoregressive. Estimating the model in first differences when the data are stationary (overdifferencing) results in an error structure that is first-order moving average (Montgomery 2001). In either case, the violation of the error structure assumptions can be resolved using standard econometric techniques. It is useful with potentially non-stationary data to examine many different potential models to account for these possible misspecifications in the face of low-power tests.

Another potential issue is that multiple non-stationary series may drift together, or be cointegrated. In this case, while each series may be non-stationary, there may exist a linear combination of them that is stationary. In this situation, the model can be represented as a vector autoregressive model (Song, Chang, and Aguilar 2011). Testing for cointegration is also necessary with a system and data such as these.

Additionally, following estimation, the curvature properties must be checked to ensure a well-behaved profit function that satisfies theoretical requirements. If curvature is not satisfied (if the Hessian matrix of second partial derivatives is not positive semi-definite), it can be imposed by a method outlined in Wiley, Schmidt and Bramble (1973). The original Hessian matrix H of the quadratic profit function is substituted by matrix AA' instead, where A is a lower triangular matrix whose elements are sums and products of the original profit function coefficients; the components of this matrix are shown in the appendix (Wiley, Schmidt, and Bramble 1973). Non-negative eigenvalues indicate a positive semi-definite Hessian.

Estimation proceeded as follows. Unit roots (non-stationarity) of all input data were checked using the augmented Dickey-Fuller test, and cointegration was also checked. The entire system was estimated using non-linear three stage least squares (3SLS) in the econometric program SHAZAM (SHAZAM Analytics 2011). The first stage instrumented for the endogenous variable Log_p by means of a linear regression on the remaining exogenous variables and a lagged value of log price. The resulting Log_p was used to generate predicted values for the variables involving log price. In all regions, multiple model specifications were run: models with input data in levels, levels with lags, and first differences, and with first- and second-order autoregressive correction. In all cases, curvature properties and evidence for remaining autocorrelation was checked follow estimation and curvature was imposed where necessary. Selection of the best fit model for each industry/region combination took into consideration evidence for stationarity, evidence for autocorrelation, significance of the coefficients required for calculating the own- and cross-price elasticities, and presence of non-negative eigenvalues (correct curvature). Once the system was estimated, elasticities were calculated within SHAZAM and tested for significant differences from zero (H_0: $\hat{\beta} = 0$). Of particular interest were the log quantity elasticity estimates with respect to input (log) price central to the market model. RMTS and RMTSET use these elasticities to determine the endogenous log price.

4.8 Estimation Results

Variables for both lumber and plywood/veneer industries were checked for non-stationarity and cointegration within SHAZAM using an augmented Dickey-Fuller test for unit roots in two forms: with and without a trend variable. Results of both tests for western Washington lumber and plywood/veneer industry input variables are shown in Table 3 and Table 4, respectively. Test statistics more negative than the indicated critical value indicate evidence for stationary data. Input data in levels showed strong evidence of non-stationarity, while the input data in first differences were, for the most part, stationary (less so with plywood input variables). The cointegration test checks the residuals of a regression equation of the input variables for non-stationarity, in order to determine if the data are stationary in combination with each other. If non-stationarity can’t be rejected, the variables are not cointegrated. Both western Washington lumber and plywood input variables did not show evidence of cointegration. Stationarity and cointegration test results for Oregon input data are not reported in Guerrero (2012, unpublished Master’s paper).

Table 3. Non-stationarity and cointegration test results for lumber.

Western Washington Lumber

Stationarity Testing: Levels

Variable	ADF Test Stat (No Trend)	ADF Test Stat (Detrended)
Profit (Profit/PPI)	-1.9429	-1.82
Lumber Quantity (Y_q)	-1.0798	-1.9614
Log Quantity ($-S_q$)	-2.1475	-2.3217
Labor Quantity ($-L_q$)	-0.68152	-2.8087
Lumber Price (Y_p/PPI)	-1.7226	-2.538
Log Price (S_p/PPI)	-1.6914	-1.3828
Labor Price (L_p/PPI)	-1.25	-1.5919
Capital (K)	0.91454	-1.1714
T-test Critical Value	-2.57	-3.13

Stationarity Testing: First Differences

Variable	ADF Test Stat (No Trend)	ADF Test Stat (Detrended)
Profit (Profit/PPI)	-3.3664	-3.3605
Lumber Quantity (Y_q)	-2.1613	-2.0028
Log Quantity ($-S_q$)	-2.7405	-2.627
Labor Quantity ($-L_q$)	-3.2763	-3.2278
Lumber Price (Y_p/PPI)	-2.6626	-2.6943
Log Price (S_p/PPI)	-3.1289	-3.042
Labor Price (L_p/PPI)	-3.7847	-3.7554
Capital (K)	-1.983	-3.0347
T-test Critical Value	-2.57	-3.13

Cointegration Testing

	Test Stat	Critical Value
No Trend	-4.1627	-4.42
With Trend	-3.5278	-4.7

Table 4. Non-stationarity and cointegration test results for plywood/veneer.

Western Washington Plywood/Veneer

Stationarity Testing: Levels

Variable	ADF Test Stat (No Trend)	ADF Test Stat (Detrended)
Profit (Profit/PPI)	-1.9215	-2.2114
Plywood Quantity (Y_q)	-1.0812	-2.3488
Log Quantity ($-S_q$)	-2.146	-1.9545
Labor Quantity ($-L_q$)	-1.8194	-0.50703
Plywood Price (Y_p/PPI)	-2.597	-2.7477
Log Price (S_p/PPI)	-1.5613	-1.1142
Labor Price (L_p/PPI)	-1.9936	-2.1545
Capital (K)	-0.14554	-1.8615
T-test Critical Value	-2.57	-3.13

Stationarity Testing: First Differences

Variable	ADF Test Stat (No Trend)	ADF Test Stat (Detrended)
Profit (Profit/PPI)	-3.1862	-3.127
Plywood Quantity (Y_q)	-3.0502	-3.09
Log Quantity ($-S_q$)	-2.565	-2.9022
Labor Quantity ($-L_q$)	-1.7709	-2.4837
Plywood Price (Y_p/PPI)	-2.8381	-2.7999
Log Price (S_p/PPI)	-3.0967	-3.0263
Labor Price (L_p/PPI)	-1.6684	-1.6029
Capital (K)	-2.9248	-2.8861
T-test Critical Value	-2.57	-3.13

Cointegration Testing

	D-F Test Stat	Critical Value
No Trend	-2.3991	-4.42
With Trend	-2.4236	-4.7

Based on the results of these tests and estimation of several model specifications (detailed in the appendix), the final model selected for western Washington lumber and plywood estimated the equation system detailed in section 4.6 with data in first differences, without corrections for autocorrelation or curvature. Evidence for autocorrelation was checked with the Durbin-Watson test for AR(1) errors. In general, the Durbin-Watson statistic reports uncorrelated errors when close to 2 for linear models. With a quadratic functional form, the Hessian matrix contains only the constants (the estimated coefficients) so curvature was checked by calculating the eigenvalues of the coefficient matrix within SHAZAM. Non-negative eigenvalues for the coefficient matrix indicated that the curvature properties of the profit function were satisfied (one eigenvalue was barely negative for plywood; not enough to compensate for the loss of degrees of freedom required to incorporate curvature corrections). Selection of the final model specification and the resulting elasticity estimates incorporated into RMTS and RMTSET was done in consultation with industry researcher and original RMTS developer, Darius Adams.

Parameter estimates and t-statistics for the final western Washington model are reported in Table 5. Shaded (grey) cells indicate parameter estimates not significant at a 95% confidence level. Comparable results for western Oregon are shown in Table 6. Western Oregon lumber estimations used a first-difference model without curvature or autocorrelation, while western Oregon plywood incorporated corrections for curvature using the Wiley, Schmidt and Bramble method. In the table, variable Y refers to the output (lumber or plywood), S the log inputs, L the labor inputs, K capacity, and T a time trend representing technology change (see Section 4.6, equations 34 – 37).

Table 5. Western Washington Model Results

Western Washington Lumber Model Results				Western Washington Plywood Model Results			
Model in first differences				Model in first differences			
Parameter	Variable	Estimate	T-Ratio	Parameter	Variable	Estimate	T-Ratio
β_0	Y_p	0.1017	1.1432	β_0	Y_p	-0.0145	-0.3719
β_1	S_p	-0.0537	-0.9740	β_1	S_p	0.0169	1.2537
β_2	L_p	-0.2608	-1.2096	β_2	L_p	0.3401	2.7535
β_{00}	Y_p^2	0.0060	7.3996	β_{00}	Y_p^2	0.0029	6.2973
β_{11}	S_p^2	0.0021	3.2677	β_{11}	S_p^2	0.0002	2.8458
β_{22}	L_p^2	0.1901	2.9814	β_{22}	L_p^2	0.0310	0.7611
β_{01}	Y_pS_p	-0.0032	-5.6268	β_{01}	Y_pS_p	-0.0009	-5.3024
β_{02}	Y_pL_p	-0.0087	-2.2778	β_{02}	Y_pL_p	-0.0025	-1.5929
β_{12}	S_pL_p	0.0058	1.4612	β_{12}	S_pL_p	-0.0010	-0.9010
β_{0k}	Y_pK	0.4586	2.2578	β_{0k}	Y_pK	0.3051	1.3024
β_{1k}	S_pK	-0.2624	-2.1026	β_{1k}	S_pK	-0.0823	-1.0172
β_{2k}	L_pK	-0.1742	-0.3780	β_{2k}	L_pK	-0.2488	-0.3244
β_{0t}	Y_pT	-0.0039	-1.0550	β_{0t}	Y_pT	-0.0001	-0.0408
β_{1t}	S_pT	0.0028	1.1876	β_{1t}	S_pT	-0.0004	-0.6558
β_{2t}	L_pT	0.0129	1.4422	β_{2t}	L_pT	-0.0088	-1.8102
β_k	K	108.8800	1.1152	β_k	K	-64.4220	-0.7198
β_t	T	-4.5649	-1.7241	β_t	T	-1.0991	-1.0792
β_{kt}	KT	-5.3732	-1.1953	β_{kt}	KT	4.1006	1.2544
β_{tt}	T^2	0.1376	2.1780	β_{tt}	T^2	0.0255	1.1074
β_{kk}	K^2	353.0000	2.8283	β_{kk}	K^2	-188.4800	-0.5847
α_0	Intercept	1.9401	0.0732	α_0	Intercept	14.5980	1.4972

Durbin-Watson Test for Autocorrelation			Durbin-Watson Test for Autocorrelation		
Eqn 34	1.9665		Eqn 34	2.0253	
Eqn 35	1.6832		Eqn 35	1.7282	
Eqn 36	1.8452		Eqn 36	1.7045	
Eqn 37	1.6828		Eqn 37	2.3459	
Coefficient Matrix Eigenvalues			**Coefficient Matrix Eigenvalues**		
0.19060	0.00724	0.00026	0.03125	0.00301	-0.00013

Table 6. Western Oregon Model Results

Western Oregon Lumber Model Results				Western Oregon Plywood Model Results			
Model in first differences				Model in first differences, curvature restrictions			
Parameter	Variable	Estimate	T-Ratio	Parameter	Variable	Estimate	T-Ratio
β_0	Y_p	0.1637	0.7834	β_0	Y_p	0.0237	0.1345
β_1	S_p	-0.0493	-0.3496	β_1	S_p	0.0479	0.7499
β_2	L_p	-0.1612	-0.3716	β_2	L_p	0.6840	2.0022
β_{00}	Y_p^2	0.0079	4.8409	β_{00}	Y_p^2	0.0142	6.4979
β_{11}	S_p^2	0.0026	2.8184	β_{11}	S_p^2	0.0018	5.6402
β_{22}	L_p^2	0.2047	3.4385	β_{22}	L_p^2	0.0208	1.0232
β_{01}	Y_pS_p	-0.0041	-4.0575	β_{01}	Y_pS_p	-0.0050	-6.3933
β_{02}	Y_pL_p	-0.0147	-3.0013	β_{02}	Y_pL_p	-0.0151	-4.9057
β_{12}	S_pL_p	0.0071	1.9636	β_{12}	S_pL_p	0.0048	3.0182
β_{0k}	Y_pK	0.8227	3.3743	β_{0k}	Y_pK	0.2759	1.0914
β_{1k}	S_pK	-0.4173	-2.7512	β_{1k}	S_pK	-0.0571	-0.6256
β_{2k}	L_pK	-0.8541	-1.9692	β_{2k}	L_pK	-0.3371	-0.7005
β_{0t}	Y_pT	-0.0082	-0.9896	β_{0t}	Y_pT	-0.0043	-0.5809
β_{1t}	S_pT	0.0040	0.7139	β_{1t}	S_pT	-0.0001	-0.0494
β_{2t}	L_pT	0.0164	0.9872	β_{2t}	L_pT	-0.0110	-0.7756
β_k	K	122.0100	1.1177	β_k	K	-98.4210	-0.9060
β_t	T	-4.7515	-0.6816	β_t	T	2.2534	0.4148
β_{kt}	KT	-0.9559	-0.2343	β_{kt}	KT	2.9093	0.5013
β_{tt}	T^2	0.1661	1.0928	β_{tt}	T^2	-0.0095	-0.0774
β_{kk}	K^2	96.1870	0.7780	β_{kk}	K^2	-93.2660	-0.9026
α_0	Intercept	0.5650	-0.2133	α_0	Intercept	-29.6750	-0.5324
Results as reported in Guerrero 2012, Unpublished Master's paper				Results as reported in Guerrero 2012, Unpublished Master's paper			

The number of insignificant parameter estimates for plywood models was not surprising given the small size of the data set and industry and the large number of parameters estimated with the systems of equations. In all cases, the key parameter needed to estimate own-price log demand elasticity was significant. Marshallian elasticities were calculated as:

$$e_{ij} = \beta_{ij} * \left[\frac{(p_j/PPI)}{x_i}\right] \; for\ i, j = output\ (y), logs\ (s), and\ labor\ (l) \qquad (39)$$

at the sample means for all input and output data. The elasticity estimates, calculated at the means of the sample data, are essential inputs into RMTS and RMTSET. The elasticity indicates the amount of price adjustment seen in the model with changes in quantity of logs demanded at the sawmills or plywood/veneer mills. This is the mechanism that endogenously sets the price for logs within the model and the mechanism by which correct signals are sent from the log market to both landowners and lumber producers. If price falls, landowners will restrict supply by postponing harvest decisions, and quantity of output will also fall. The resulting price correction results in a new equilibrium price and quantity of logs demanded and lumber produced.

Cross- and own-price input elasticity calculations and results for both lumber and plywood industries are shown in Table 7 for western Washington and Table 8 for western Oregon. Grey cells indicate elasticity estimates insignificant at a 95% confidence level. The key own-price log demand elasticity is significant in both lumber and plywood/veneer industry estimations. Several of the other elasticities were not, particularly in the plywood/veneer industry. That industry is not as robust or as large as the lumber industry in western Washington and faces declining capacity and closing mills.

Table 7. Elasticity results for western Washington.

Western Washington Lumber Results

Elasticities		Estimate	Apx. p-Value
e_{yy}	β_{00} (Y_p/Y_q)	0.5000	0.000
e_{sy}	β_{01} (Y_p/S_q)	0.4628	0.000
e_{ly}	β_{02} (Y_p/L_q)	0.2081	0.023
e_{ys}	β_{01} (S_p/Y_q)	-0.2913	0.000
e_{ss}	β_{11} (S_p/S_q)	-0.3223	0.001
e_{ls}	β_{12} (S_p/L_q)	-0.1499	0.144
e_{yl}	β_{02} (L_p/Y_q)	-0.0866	0.023
e_{sl}	β_{12} (L_p/S_q)	-0.0991	0.144
e_{ll}	β_{22} (L_p/L_q)	-0.5451	0.003

Western Washington Plywood Results

Elasticities		Estimate	Apx. p-Value
e_{yy}	β_{00} (Y_p/Y_q)	0.6328	0.000
e_{sy}	β_{01} (Y_p/S_q)	0.5848	0.000
e_{ly}	β_{02} (Y_p/L_q)	0.1515	0.111
e_{ys}	β_{01} (S_p/Y_q)	-0.3177	0.000
e_{ss}	β_{11} (S_p/S_q)	-0.2547	0.004
e_{ls}	β_{12} (S_p/L_q)	0.0965	0.368
e_{yl}	β_{02} (L_p/Y_q)	-0.0685	0.111
e_{sl}	β_{12} (L_p/S_q)	0.0804	0.368
e_{ll}	β_{22} (L_p/L_q)	-0.2346	0.447

Table 8. Elasticity results for western Oregon

Western Oregon Lumber Results			
Elasticities		Estimate	Asy. t-Value
e_{yy}	β_{00} (Y_p/Y_q)	0.4434	4.841
e_{sy}	β_{01} (Y_p/S_q)	0.3941	4.058
e_{ly}	β_{02} (Y_p/L_q)	0.3336	3.001
e_{ys}	β_{01} (S_p/Y_q)	-0.2528	-4.058
e_{ss}	β_{11} (S_p/S_q)	-0.2652	-2.818
e_{ls}	β_{12} (S_p/L_q)	-0.1750	-1.964
e_{yl}	β_{02} (L_p/Y_q)	-0.0716	-3.001
e_{sl}	β_{12} (L_p/S_q)	-0.0586	-1.964
e_{ll}	β_{22} (L_p/L_q)	-0.4052	-3.439

Western Oregon Plywood Results			
Elasticities		Estimate	Asy. t-Value
e_{yy}	β_{00} (Y_p/Y_q)	0.5541	6.498
e_{sy}	β_{01} (Y_p/S_q)	0.5916	6.393
e_{ly}	β_{02} (Y_p/L_q)	0.2196	4.906
e_{ys}	β_{01} (S_p/Y_q)	-0.3431	-6.393
e_{ss}	β_{11} (S_p/S_q)	-0.3786	-5.640
e_{ls}	β_{12} (S_p/L_q)	-0.1224	-3.018
e_{yl}	β_{02} (L_p/Y_q)	-0.0799	-4.906
e_{sl}	β_{12} (L_p/S_q)	-0.0769	-3.018
e_{ll}	β_{22} (L_p/L_q)	-0.0409	-1.023

As reported in Guerrero, unpublished Master's paper

The RMTS and RMTSET models use the estimated coefficients from the econometric model to define the sawlog demand at the mill and the own-price elasticity estimate for log supply demand at the mill. The coefficients used are β_{01}, the coefficient for output price times log price; β_{11}, the coefficient for log price squared; β_{12}, the coefficient for log price times labor price; and β_{1k} and β_{1t}, coefficients for log price times capital and technology (the time trend) respectively. These parameters, along with the elasticity estimates, define log demand within the model. The final equations as used in the version of RMTSET used in this dissertation are:

$$\frac{d\pi}{dS_p} = -S_q(p, w, K, t)$$

$$= -0.37599 - 0.00414Y_p + 0.002568S_p + 0.007079L_p - 0.417300K + 0.003972t \quad (for\ lumber) \tag{40}$$

$$= -0.30316 - 0.00499Y_p + 0.00182S_p + 0.00480L_p - 0.5714K - 0.00013t \quad (for\ plywood\ and\ veneer) \tag{41}$$

Selected estimates of own-price elasticities of logs in the lumber industry were inelastic in both western Oregon and western Washington, at -0.2652 and -0.3223, respectively. Estimated results for the plywood industries of western Oregon and western Washington were similar, -0.3786 and -0.2547. These estimates are somewhat similar, albeit smaller, to results reported in other studies; for example, a study of the coastal British Columbia (Canada) softwood lumber industry found own-price roundwood elasticity of -0.55 (Latta and Adams 2000).

5. Biomass Technology Development

5.1 Introduction

Biomass for energy production can focus on many outputs at many scales of operation; for example, stand-alone plants generating electricity only; large plants converting biomass into liquid fuels; cogeneration of steam with electricity for industrial purposes; or small-scale heating projects at single institutions such as schools or hospitals (Nicholls et al. 2008). Electricity-only generation biomass facilities average about 20 MW in size, but it is difficult for biomass to compete with other renewable energy sources in terms of cost per kilowatt-hour generated, and uncertain supplies have led to closures of plants in previously high-biomass use states like California (Nicholls et al. 2008; Bain and Overend 2002). In addition, electricity-only generation is an inefficient use of biomass; significantly more energy recovery per volume of biomass can be achieved through either heat or combined heat and power generation.

A competing proposed use of cellulosic material is for liquid fuels, including ethanol. Although targets for cellulosic ethanol production have been set in the U.S. and there is industry optimism about the role that cellulosic biofuels can play, large-scale production of liquid fuel from woody cellulosic biomass has not been widely successful on a commercial scale (Doering 2014). Most of the current activity around cellulosic biofuel production exists in research or demonstration scale conversion plants utilizing corn, wheat, or other fast-growing grass crops as feedstock (Advanced Ethanol Council 2012). The NARA project, along with other US Department of Agriculture funded grants, seeks to further the development of both the technology and the understanding of the feasibility of this use of woody biomass. The technical and chemical specifics of the conversion of wood to liquid biofuels and co-products is being developed within NARA under a single large-scale facility model that receives hundreds of thousands of bone dry tons of harvest residue a year. The most likely scenario for such a facility is a location at a current or recent pulp or paper mill (some existing infrastructure could be repurposed and there is access to large amounts of water) in an area with access to cheap shipping options (rail, barge, and/or pipeline for liquid product outputs) that is also in a region of high timber harvest (feedstock generation). In the C2P region, only a handful of locations fit these criteria; as noted in Section 1.3, the NARA team selected two locations in Washington as possible sites for such a plant. For Western Oregon, in keeping with the general criteria used by NARA in selecting refinery locations, I selected Springfield, Oregon as a potential refinery site to use in this analysis. Springfield is a large town with a significant forest industry presence: several lumber mills, a plywood mill, and a Kraft process paper mill primarily utilizing sawmill residues from the area are all in operation. Springfield has rail and interstate access as well, and it is likely that there is a high degree of social acceptability for emerging forest products technologies and the related development that would need to occur.

5.2 Alternate Biomass Technologies

Direct delivery of massive amounts of biomass from the woods to a large central refinery certainly is one way to utilize currently unused material and capture more of the value of the residual wood. It also furthers energy independence goals within the U.S. However, the development of large-scale technology in established cities with transportation advantages and existing infrastructure – places likely to already benefit from that competitive advantage – does little to help rural communities reeling from changes in forest policy, larger macroeconomic cycles, and technology changes that have led to job losses and mill closures.

The idea of using this material as a rural development tool has been proposed by many in the forestry and rural policy community. Idle rural infrastructure (closed mill sites) or the development of new infrastructure could be used to establish intermediate processing facilities, where biomass direct from the woods could be altered in a number of ways, creating higher quality and higher value products for use in multiple applications. Material chipped or ground in the woods could be dried and screened to create a more consistent, desirable product; material could be transferred to lower cost transportation (rail); or altered through densification, pyrolosis, or other processes and converted into alternative products such as pellets or biochar. This model of intermediate processing facilities (depots) designed to capture some of the benefits of using biomass in rural areas is the focus of RMTSET with extensions.

These technologies and rural development uses are still emerging as options within the larger forest products industry. There are few existing facilities that could be used to parameterize these processing centers within RMTSET. Example depot formulations and establishment and operating cost estimates for three types of depots were generated by David Smith at Oregon State University (personal communication, February 26 2014). Each type offers potential for rural development while at the same time allowing for support of the large refinery model that is the focus of the NARA project. The flexibility of the RMTSET model allows for the analysis of many types of intermediate processing centers by alteration of initial establishment and operating costs. Three example depots are described briefly below, and RMTSET with extensions is used to answer the question: What is the maximum depot start-up and operating costs that can be supported at the price of biomass that is likely to be offered given an existing refinery?

A transshipment depot is a limited function facility that receives forest-ground biomass direct from the woods in single-trailer chip trucks. At the depot, material is either used locally or transferred to high-capacity trucks (double trailers) or rail cars for delivery to the bio-refinery. The motivation for establishment of this type of depot is to reduce the overall hauling cost from the woods to the bio-refinery, by taking advantage of higher capacity transportation once the material reaches an intermediate location between the woods and the refinery. If the cost savings for the second leg of the journey between depot and bio-refinery is great enough per volume shipped, it would allow for the bio-refinery to economically draw feedstock material from a wider range.

A drying/screening depot would increase functionality by adding a bed dryer and biomass-fueled boiler to a transshipment option, with the objective of bringing the moisture content of the biomass down from approximately 45% to 20%. The processed material is then cheaper to ship and/or is a more consistent, higher quality product (if also screened). Similar to the transshipment depot, the processed material can be loaded into high-capacity trucks or rail cars for delivery to the bio-refinery or used locally. In addition, the depot could provide steam heat for additional applications from the bed dryer, although this side use was not modeled within RMTSET with extensions.

A third potential depot is one that merchandises a wide variety of material for its best use. The depot receives all non-sawlog material and produces a variety of products, from firewood to poles to raw chips to biochar, with a goal of creating a mix of products that generates a return of $100 per bone dry ton of input material. In this case only a small percentage of the input material would move from the depot to a bio-refinery. In Wallowa County, a system similar to this has recently opened without the presence of a purchasing bio-refinery for processed chips (Nils Christofferson, Wallowa Resources, personal communication, May 12 2014). The overall profitability of this type of system remains to be analyzed over time.

5.3 Potential Locations for Processing Centers

One of the interesting policy questions that can be addressed with RMTSET with extensions is the spatial locations where depots would be economically feasible. For the development of biomass use to be sustainable over time, it needs to be a market-driven solution that can exist without intervention or subsidies; it will necessarily mean development in some places but not others. This tradeoff of where feasible development might occur will help to illuminate a critical question with the idea of using biomass technology as a rural development tool: Will it potentially help the places that have been most affected by changes in the forest products industry?

RMTS uses 43 known demand locations for sawlogs and pulpwood in western Oregon (Table 9). These demand locations include operating sawmills, plywood/veneer mills, and pulp/paper mills. To develop a set of possible locations for depot establishment within the model, I gathered information from several sources, including information on former mill locations and small-scale operations generated as part of the profit function input data process (section 4.5). As recently as 1980, there were 405 operating mills in the entire state, so most communities in Oregon have a legacy of wood processing at some point in time. I also wanted to ensure that the depot choice set incorporated into RMTSET with extensions captured a wide geographic spread as well as places that have been negatively affected by changes in the forest products industry, yet also have enough population and possible infrastructure to support an investment. Using that goal, along with information about current and historic processing locations, I developed a set of 65 possible depot locations to incorporate into RMTSET with extensions (Table 9). These possible depot locations were compiled by combining the current mill locations from RMTS with identified locations compiled for NARA by the University of Montana's Bureau of Business and Economic Research as well as the U.S.D.A. Forest Service reports (Spelter, Alderman, and McKeever 2007). Duplicates and small 'boutique' or mobile sawyers were removed. Rural locations without mills in any list but of possible interest for policy analysis were then added in a way to represent as wide of a geographical spread across the Westside of Oregon as possible. For example, although Oakridge's mill closed decades ago, its location within extensive federal forests creates an opportunity for interesting policy analysis; several other locations along the west side of the Cascade Range were selected for similar reasons. Several towns were also selected to represent tribal communities that may also be useful for policy analysis. Springfield is excluded from the potential depot locations, as it is assumed in the model scenarios that a bio-refinery has already been established there. RMTSET with extensions selects from any of these 65 "mill primordia" as locations in which to invest and establish depots where it makes an overall positive contribution to consumer and producer surplus (the objective function). The current demand locations listed in Table 9 are lumber mills only if not otherwise designated. The potential depot locations that are italicized are destinations that are already demand centers within RMTS/RMTSET due to the presence of currently operating lumber, plywood/veneer, or pulp/paper facilities.

Table 9. Locations of demand modeled in RMTSET.

Existing Demand Locations in RMTSET

Banks
Brookings (L,P)
Carver
Cave Junction
Clatskanie (L,PP)
Coburg (L,PP)
Coburg
Coos Bay
Coquille (P)
Corvallis
Cottage Grove
Dallas
Dillard (L,P)
Estacada
Eugene (L,P)
Forest Grove (L,PP)
Foster (P)
Glendale (L,P)
Glide
Grants Pass
Harrisburg
Lebanon
Lyons
Medford
Mill City (L,P)
Mist
Molalla
Monroe
Norway
Noti
Philomath
Portland
Riddle (L,P)
Roseburg (L,P)
Springfield (L,P,PP)
St Helens
Sutherlin
Tillamook
Toledo (L,PP)
Warrenton
White City (L,P)
Willamina (L,P)
Winchester

L=Lumber
P=Plywood
PP=Pulp/Paper

Potential Depot Locations

Albany
Ashland
Astoria
Bandon
Banks
Blue River
Brookings
Carver
Cascade Locks
Cascadia
Cave Junction
Central Point
Clatskanie
Coburg
Coos Bay
Coquille
Corvallis
Cottage Grove
Dallas
Dillard
Estacada
Eugene
Forest Grove
Foster
Gale Creek
Garibaldi
Gaston
Glendale
Glide
Grand Ronde
Grants Pass
Green
Harrisburg
Lebanon
Lyons
Mapleton
Medford
Mill City
Mist
Molalla
Monroe
North Plains
Norway
Noti
Oakridge
Oregon City
Philomath
Portland
Powers
Reedsport
Riddle
Roseburg
St. Helens
Sheridan
Siletz
Sutherlin
Sweet Home
Tillamook
Toledo
Vernonia
Warrenton
White City
Willamina
Winchester
Wolf Creek

5.4 The Role of Federal Lands in Biomass Supply

As discussed previously, harvestable biomass generation within RMTS/RMTSET is modeled as a ride-along to market-driven sawlog harvest, given the current inventory, growth of inventory into the future, and known management practices in the region. This includes harvest of sawtimber on both private and public lands, although public land supply is not market-driven. The rate of public harvest has declined dramatically since the injunction against harvest that was enacted in 1991 as a result of the Dwyer decision. Despite an 800 million board foot harvest target set in the Northwest Forest Plan for National Forests and BLM lands in the region, actual harvest since 1996 has been far less, typically around half that amount in any given year (Niemi, Whitelaw, and Johnston 1999; Grinspoon and Phillips 2011). This means that there is far less biomass material available as supply that originates on federal land than on private land, simply because the harvest actions are less frequent on federal lands.

The source of the biomass matters, however. When the Congress enacted the Energy Independence and Security Act, they clearly defined renewable fuels as any made from non-federal biomass sources (110th U.S. Congress 2007; Gibson 2009). Woody biomass feedstock coming from federal lands does not count as renewable in fuel production. As a result, fuel derived from any federal biomass source is not eligible for Renewable Identification Numbers.

Renewable Identification Numbers (RINs) are assigned to biofuel produced that meets the 2010 Renewable Fuel Standards implemented by the Environmental Protection Agency (EPA). RINs function much like carbon credits: companies can purchase RINs to meet renewable requirements from producers of renewable fuels. The price of a RIN per gallon is set in the market; types of renewable fuels in large-scale production have a large supply of RINs, so the price is accordingly lower. Given the very small contribution of woody biomass to the renewable fuel supply, the expectation is that RIN credits may be worth a significant portion of the sale price per gallon. For the production of woody biomass based fuels, this additional income from the sale of RINs can help offset the higher cost of producing the fuel from biomass as compared to fossil fuels. The prospective sale income from RINs will likely be essential in the feasibility of biofuel production from woody biomass and for this reason scenarios modeled within NARA on feedstock supply do not incorporate the use of biomass from federal lands.

This exclusion of federal land biomass from renewable fuel standards and RIN credits is problematic if one of the hopes for developing biomass markets is that it will make wildfire risk reduction fuel treatments more cost-effective. While federal sources can be used in any application where the sale of RINs is not involved, such as local use for institutional boilers, it may place a serious limitation on the incentive that large-scale production such as that envisioned by NARA can provide to the market for non-merchantable material. The difference in the increase in price necessary to deliver the minimum amount of biomass to a large facility with and without federal lands is the opportunity cost of this policy. In addition, it is useful to ascertain if there is a difference in optimal depot location if federal lands are included in biomass use, or if federal land harvest approached the level set in the Northwest Forest Plan. These policy scenarios were explored within RMTSET with extensions and the results are discussed in Chapter 6.

5.5 Modeling Depots within RMTSET with Extensions

Depots are modeled within RMTSET with extensions as modular technologies that can be scaled up or down in capacity increments. The first capacity increment is the equivalent of one shift of a hypothetical depot; a second shift doubles capacity and a third shift triples it. The model can select from these three steps for either a 25,000 bdt/yr (with 50,000 and 75,000 bdt/yr steps for two-shift and three-shift capacity, respectively). Only one depot can be built in any particular location.

Depots cost a fixed amount per bone dry ton of capacity to establish within the model. They can scale up or down in the designated capacity increments as is optimal given the supply of biomass being generated by conventional harvest of sawtimber. Adjusting the capacity cost required to establish depots allows for elucidation of the maximum cost per unit of input capacity for a depot type to be feasible to construct, given a market price for biomass established by the refinery.

Depots may function in one of two ways. Under the NARA vision, depots exist to supply densified (dried or otherwise pre-processed) material to a large-scale refinery, the dependent depot scenario. An alternate possibility, however, is a stand-alone depot that provides material to local uses, such as institutional boilers (independent depots). With the development of these local uses for biomass, it might be feasible for the depots to exist to gather and supply material locally, regardless of demand for a densified product at a bio-refinery. Modeling the maximum establishment cost in dollars per bone dry ton of capacity allows for analysis of the feasibility of stand-alone depots.

In this section, I describe current dollar estimates of establishment and operating costs for the various types of depots and capacities of depots discussed previously, as generated for the project by David Smith (personal communication). I did not model the different depot types explicitly. Instead, the model was solved for a range of costs in order to identify thresholds at which depots become financially feasible. All depot costs are presented in current ($2014) dollars, deflated within the model to match the base year for all other costs. The costs are presented here as illustrations of the types of emerging technology of potential interest in the development of biomass utilization markets.

Establishment of a transshipment depot, assuming a former industrial site exists, would potentially require a truck scale and dump, a rail spur and loading station, a truck reload station, a pile dozer, two front end loaders and a fork lift. The best case cost estimate for this facility is $700,000 in capital cost for a facility capable of processing 25,000 bdt/year of biomass (100 bdt/day). Annual operating costs cover 3 employees, maintenance and labor, fuel, permits, electricity, and general operating supplies and are estimated at $289,000 under a best case scenario.

For a drying station depot, the best case capacity cost is estimated at $3,000,000 for a depot that receives 40,000 bdt/year of material and outputs 32,000 bdt/yr (the difference being the material used to fire the dryer). Annual operating costs for the best case scenario are $480,000 and include employment for four employees per shift. The integrated merchandising depot carries a best case capacity start-up cost estimate for a system like this is estimated at $6.4 million with operating costs of $1.1 million per year. The expected employment in this system is the highest among all the depot types at 13 FTE for a facility that processes the equivalent of 75,000 bdt/year.

Biomass-related costs used within the model are: $17.50 per bone dry ton (bdt) for comminuting and loading and a pile-to-landing cost of $20 per bdt. These are assumptions based on estimates from other NARA team partners. To assess the sensitivity of depot establishment to different costs, RMTSET incorporates an operating cost associated with processing the material and other variable costs related to the amount of material a facility handles, calculated on a per-unit basis for every bdt of input material passing through a depot. This operating cost also can represent depreciation of the equipment used in the depot as it is related to amount of use (and therefore amount of processing that occurs). Establishment costs are charged within the model as a constant, regardless of capacity, because functional capacity was modeled as adding one or two work shifts to a set depot size. Example cost components and estimates for a transshipment depot are detailed in Table 10.

Table 10. Example cost components for a basic transshipment depot.

Cost component	Cost estimate
Equipment: 3-acre site, Truck scale & dump, Rail spur & loading station, Truck reload station, Pile dozer, front end loaders, fork lift, maintenance tools, fire protection, power distribution, office	Best Case Cost (Total): $700,000 Cost per bdt of capacity: 25,000 bdt capacity (one shift): $28 50,000 bdt capacity (two shifts): $14 75,000 bdt capacity (three shifts): $9
Operation: Labor (1 supervisor, 2 operators/shift), Maintenance parts and labor, rolling stock fuel, operating supplies, electric power, permits and insurance (legal)	Best Case Cost (Total): $289,000/year

The price of biomass at both the refinery and the depots was set exogenously and was varied up and down to trace out a biomass supply curve for a given destination location.

Transport costs were developed, as a part of NARA research, between plots and destinations (mills and all potential refinery/depot locations) using actual road networks and an assumed distance between possible landings at each plot and the nearest road. Travel time and speed varied between road types (e.g. forest roads, minor highways, and major highways). For biomass, travel between the plot and the first destination (whether refinery or depot) assumed 50% moisture content and single-van chip trailers. Travel between depots and the refinery for the modeled processed product assumed 35% moisture content and double-trailers. With travel between the depot and refinery primarily on major highways, the haul cost model also included savings for higher speeds of travel and lower rolling resistance for the trucks.

6. Results: Model Outputs

6.1 Introduction

The model was programmed and run in GAMS, the General Algebraic Modeling System software program (release version 24.1.3; GAMS Development Corporation 2014). GAMS is a language compiler, a suite of solvers, and various productivity tools specifically designed for modeling linear, nonlinear, and mixed-integer optimization problems. The base model (RMTS) was programmed primarily by Darius Adams and Greg Latta and RMTSET with extensions was adapted from that. The CPLEX solver was used for both the linear program (RMTSET, which models a bio-refinery and no depots) and the mixed-integer program (RMTSET with extensions).

Optimization program solutions can be heavily influenced by the terminal condition or lack of one. All versions of RMTS include a terminal condition that models continued sawlog harvest at a level determined by an application of Von Mantel's formula (section 3.5). Still, it is important in modeling to run the program for far longer than the reasonable period of analysis, to ensure that final conditions do not unduly influence the solution. In all cases the model was run for a 55-year time horizon, from 2005 to 2060. The window typically used for large investments is 20 years. Policy conclusions focus on the results from this initial 20-year time horizon but results from the full 55-year modeling horizon are shown in tables and graphs when specified. The model uses five-year time periods.

This chapter details the modeled results for several different scenarios. Section 6.2 shows the results from a bio-refinery only scenario that addresses the overall feasibility of the creation of jet fuel in western Oregon from harvest residues (Eq. 18.2).

Section 6.3 models the overall feasibility of establishing independent depots, the optimal locations of independent depots established to supply local biomass demand, and the variations in establishment costs that allow that to happen (Eq. 18.3, θ=1). Section 6.4 models the alteration in optimal dependent depot location that emerges with the inclusion of both current and with varying levels of increased federal harvest as a source for biomass, while section 6.5 looks at the feasibility of dependent depots and the conditions under which depots can feasibly provide refined biomass only for bio-refinery use (Eq. 18.3, θ=0).

6.2 Biomass Supply Curve for a Springfield, Oregon Refinery

The first scenario modeled with RMTSET was a bio-refinery located in Springfield, Oregon utilizing field-ground or chipped biomass direct from the woods. For this I was interested in establishing what the price offered by the refinery would need to be in order to generate a supply of at least 750,000 bone dry tons (bdt) of biomass annually, roughly the minimum amount modeled by NARA for a bio-refinery. Is a refinery of this magnitude feasible in western Oregon? If such a refinery existed, what price would it need to offer for field-ground biomass to obtain an adequate supply?

A supply curve for woody biomass delivered to the bio-refinery in Springfield was constructed by solving the model for a very low price offered for delivered biomass, then repeatedly solving the model using incrementally higher prices. The resulting supply curve, shown in Figure 8 (page 105), is based on assumptions of the collection costs detailed previously and transport of field-ground biomass at a moisture content of 50%, with only single-trailer truck transport from the landings to the bio-refinery, and, given that a major component of the profitability of the bio-refinery may come from the sale of

RIN credits from the manufacture of renewable fuels, without the inclusion of any material from harvest on federal lands. At high enough prices (approximately $90/bdt), biomass markets may compete with traditional uses of chips for pulp.

Results calculated over the initial 20 years of the modeling horizon show that the bio-refinery would need to offer more than $65 per bdt to generate an average annual supply of at least 750,000 bdt to Springfield (the red line in Figure 8). A facility requiring 1,000,000 bdt a year for operating efficiency would need to pay more than $70/bdt for biomass. The gradual increase in quantity delivered reflects the increasing economic feasibility of recovery from locations farther away as price increases. It is possible that at very high prices, delivery of biomass will increase sharply as all areas become economically feasible, then flatten out as all sources are exhausted.

To explore the potential effect of federal timber harvest on biomass supply, I included federal timber harvest at current levels. This supply curve is shown by the blue line in Figure 8. The inclusion of federal lands brought only slightly more biomass into the bio-refinery at higher prices (or conversely, a slightly lower price could be offered to procure the minimum amount needed). The inclusion of federal lands does not dramatically impact the biomass available because biomass is modeled as a ride-along to timber harvest, and there is very little harvesting occurring on federal land in a business-as-usual scenario. For example, at $65/bdt offered at the refinery, an annual average of 740,029/bdt is delivered over the entire modeling horizon without federal lands sources, while the inclusion of federal land sources increases it to only 770,384/bdt delivered.

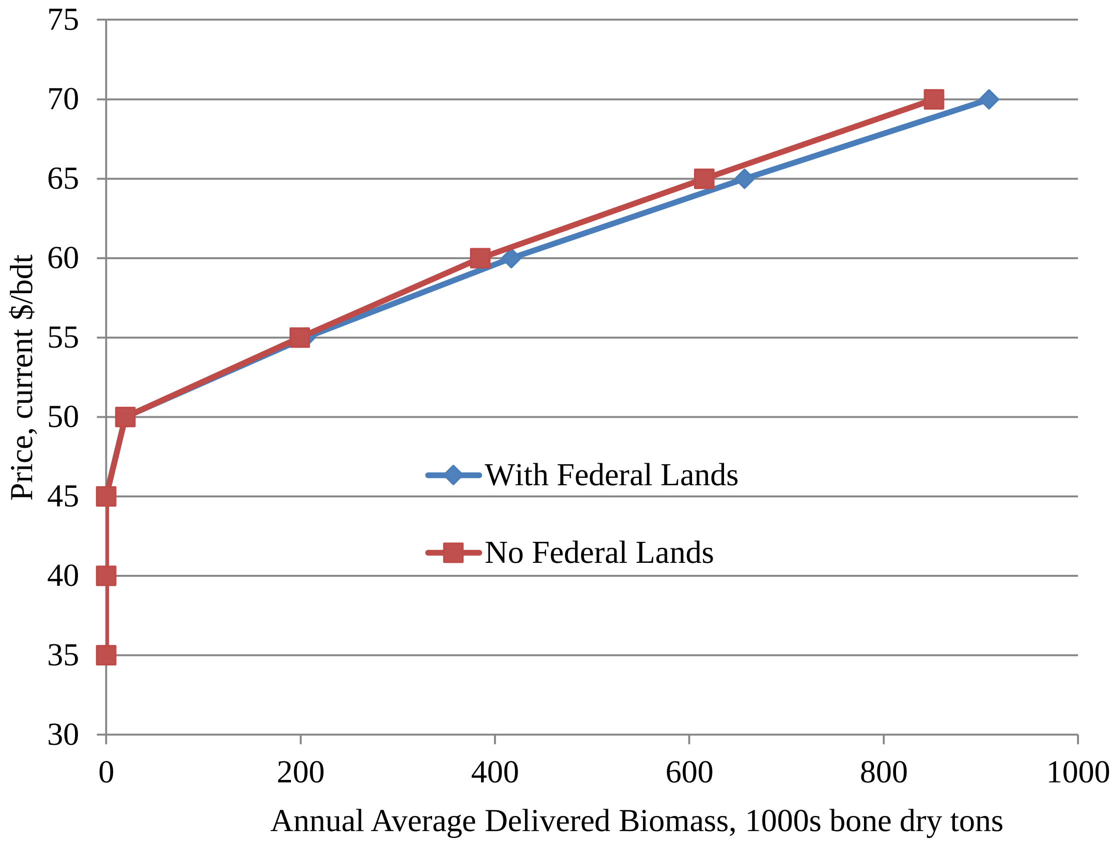

Figure 8. Biomass Supply Curve for Springfield, Oregon (Avg. annual amounts, 2005 – 2025).

This graph shows only the average annual amount of biomass delivered to the bio-refinery between 2005 and 2025 for each given price. There are temporal variations within these averages as well; these are shown in Table 11 below. At $65/bdt, none of the periods within the first 20-year analysis time horizon deliver the 750,000 bdt required by the bio-refinery; the average is above the minimum required only when later periods are included. Enforcing a minimum delivery within RMTSET would ensure that this minimum criteria was met in all periods, but it would be at a reduction in the objective function over the surplus-maximizing solution shown here. The amounts shown in Table

8 are for the non-federal land supply scenario only. Grey cells indicate periods outside the main analysis horizon (greater than 20 years out). Although the relevant planning horizon focuses on the initial 20 years, the amount of biomass available increases over time.

Table 11. Biomass deliveries, bio-refinery only.

	Price per bone dry ton at bio-refinery				
Yearly Average	$70	$65	$60	$55	$50
2005 - 2010	789,180	659,651	462,508	294,079	6,655
2010 - 2015	986,114	659,110	405,890	225,594	35,197
2015 - 2020	894,284	673,496	322,290	156,747	15,405
2020 - 2025	737,319	468,623	349,244	120,223	21,908
2025 - 2030	865,101	571,143	330,876	119,542	29,170
2030 - 2035	872,728	548,597	346,720	190,121	0
2035 - 2040	1,059,122	764,363	491,214	213,930	15,811
2040 - 2045	1,317,448	904,694	683,748	359,985	61,106
2045 - 2050	1,285,026	960,939	536,378	287,676	73,184
2050 - 2055	1,320,421	967,163	552,618	414,906	75,854
2055 - 2060	1,300,750	962,535	777,905	415,136	124,371
2005 - 2060	1,038,863	740,029	478,127	254,358	41,696
2005 - 2025	851,724	615,220	384,983	199,161	19,791

At a bio-refinery price of $65/bdt, material flowing into Springfield is sourced from within its own county (Lane) and from six adjacent and nearby counties (Benton, Douglas, Lincoln, Linn, Marion, and Polk). High transportation costs make deliveries from more distant counties uneconomical. Again, the inclusion of federal lands does not dramatically change the available amount, and has no change on the optimal source county locations (Table 12).

Table 12. Source of biomass delivered to Springfield.

County of origin for delivered biomass ($65/bdt): No Federal Lands

Yearly Average	Benton	Douglas	Lane	Lincoln	Linn	Marion	Polk	Total
2005 - 2010	60,312	158,176	230,571	39,499	122,435	3,603	45,054	659,651
2010 - 2015	69,126	132,127	254,456	3,088	193,251	1,881	5,182	659,110
2015 - 2020	58,461	205,209	189,810	3,076	173,336	16,124	27,481	673,496
2020 - 2025	36,861	98,935	212,640	9,222	108,925	0	2,042	468,623
2025 - 2030	38,320	153,929	192,865	105,240	76,751	0	4,038	571,143
2030 - 2035	35,772	48,854	323,918	19,681	77,174	0	43,198	548,597
2035 - 2040	51,741	146,528	307,135	22,983	160,671	36,651	38,655	764,363
2040 - 2045	69,218	350,545	276,892	41,582	117,773	8,575	40,109	904,694
2045 - 2050	83,905	362,539	333,472	61,870	85,567	0	33,586	960,939
2050 - 2055	100,844	326,026	386,514	8,729	110,119	27,507	7,424	967,163
2055 - 2060	93,470	151,048	503,198	49,226	147,045	0	18,547	962,535
2005 - 2060	63,457	193,992	291,952	33,109	124,823	8,576	24,120	740,029
2005 - 2025	56,190	148,612	221,869	13,721	149,487	5,402	19,940	615,220

County of origin for delivered biomass ($65/bdt): With Federal Lands

Yearly Average	Benton	Douglas	Lane	Lincoln	Linn	Marion	Polk	Total
2005 - 2010	62,651	158,187	314,236	40,386	126,666	3,603	45,079	750,807
2010 - 2015	71,702	132,047	266,956	3,963	197,775	1,881	5,193	679,517
2015 - 2020	62,725	205,953	201,493	3,949	178,118	16,124	27,499	695,861
2020 - 2025	39,488	111,174	223,583	10,092	114,233	0	2,061	500,630
2025 - 2030	40,293	159,361	204,112	106,662	80,558	0	4,057	595,043
2030 - 2035	37,997	57,613	334,951	19,695	80,696	0	43,217	574,170
2035 - 2040	53,917	152,519	319,183	22,976	164,875	36,651	38,676	788,796
2040 - 2045	71,349	350,571	289,220	42,446	120,577	8,575	40,128	922,866
2045 - 2050	86,274	362,513	346,531	62,733	90,163	0	33,458	981,673
2050 - 2055	102,911	330,435	397,462	9,592	114,535	27,507	7,608	990,049
2055 - 2060	95,600	163,953	515,769	49,636	151,289	0	18,567	994,815
2005 - 2060	65,901	198,575	310,318	33,830	129,044	8,576	24,140	770,384
2005 - 2025	59,142	151,840	251,567	14,597	154,198	5,402	19,958	656,704

6.3 Establishment and Locations of Independent Depots

As modeled in RMTSET, the bio-refinery exists as a fixed demand center, with no associated costs (apart from the actual feedstock-related costs of piling, processing, and transporting the biomass). The financial feasibility of bio-refinery construction and overall profitability is being determined through a techno-economic analysis conducted by NARA. If the bio-refinery appears profitable, given the price of the feedstock and all other inputs and the price realized through the sale of biofuel and co-products, it is possible that it would be established. RMTSET was used not to assess the overall financial feasibility of such a facility, but rather to determine what price the bio-refinery would need to be willing to pay to generate the required supply of biomass (section 6.2).

Using RMTSET to assess the financial feasibility of local depots, and the potential for depots to influence community conditions in rural areas, was the primary goal of this dissertation. That was done through the inclusion of establishment and operating costs for depots, transportation costs for material flowing to depots, and the supply of biomass generated as a byproduct of timber harvest in the region, which allows the model to choose to open depots in any location where the contribution to the objective function from a depot is positive. Depots have a net positive contribution to the objective function (overall welfare) whenever the price paid per unit of delivered biomass is greater than the sum of the processing, transport, and operating cost of the depot, and the establishment cost, over the life of the model. Different establishment and operating costs were used to mimic increasing levels of depot investment (e.g. a transshipment depot as compared to a drying station depot). Establishment costs were calculated as a one-time cost when the capacity is installed in dollars per bone dry ton of capacity built, while operating costs were assessed in the model as dollars per bone dry ton of material passing into the depot over the entire modeling horizon.

Depots differed from the bio-refinery in the model in key ways. The refinery is assumed to exist and no establishment or processing costs that occur at the bio-refinery are accounted for in the model. The bio-refinery accepted any amount of material; the implicit assumption was that the fuel producing technology was continuously scalable or that there was free disposal of any unneeded product. Depots, on the other hand, were modeled with potential capacity increments with a maximum capacity for any one depot. Once the capacity level is established, the depot is free to accept any level of biomass below the maximum. In simulations, the amount of biomass received at any one depot sometimes fluctuated as source locations on the margin of feasibility were harvested at different points in time. Depot capacity was established in any model period and was also allowed to change at any time over the modeling horizon.

As discussed in section 3.7, two different depot scenarios were modeled: independent and dependent depots. The independent depot scenario assumes that there is a local demand for gathered and potentially processed biomass, perhaps for industrial heat or small-scale electricity generation purposes, and assesses the feasibility of establishing depots on their own, without reliance on provision of a product to the bio-refinery. In these scenarios, depots may potentially aid local communities in the employment of labor required to operate the depot, as well as in facilitating the provision of biomass for local uses. In each the existence of the bio-refinery was also assumed, and one market price for biomass at all demand centers of biomass (bio-refinery and depots) was exogenously set, as described in the next section. A bio-refinery in this case competes with the depots for biomass in some areas and does not directly influence rural development.

Dependent depots (results discussed in the next section) exist to facilitate the delivery of biomass to the bio-refinery in a cost effective manner. In these scenarios, dependent depots directly influence rural communities by providing the impetus for the establishment of processing centers that are closer to the source material. With the depots providing material only to the bio-refinery, the bio-refinery in this case provides the demand that enables the depots to be feasible, rather than competing with them as biomass demand centers.

In all depot scenarios (independent and dependent), the model incorporates an establishment and an operating cost. The operating cost can be adjusted in order to represent different types of depots. For example, a low price can represent simply the cost to unload and reload the material in a transshipment depot. Higher costs in dollars per unit of input material can represent other intermediate processing activities such as drying or screening to produce a densified or higher quality product. In all scenarios, the amount of the operating cost assumption is specified, but the particular operating activities could include any number of things and is not specified.

6.3.1 Establishing an Offered Price for Biomass

The remainder of the modeled scenarios assumed that all depots and the bio-refinery offered the same price for forest-chipped biomass. To select a reasonable and interesting biomass price for policy scenarios, I solved the model for a range of biomass prices. The establishment cost of $1 per bone dry ton per unit of capacity used is equivalent to almost a fully subsidized construction cost. Operating costs of $2 per bone dry ton of input material were less than the cost estimated for the lowest priced depot under the best case scenario and represented an unrealistically inexpensive system, but were useful for generating the maximum level of stand-alone (independent) depot establishment that would be feasible given the other assumptions in the model (example costs detailed in Table 10).

Biomass shipments to the bio-refinery and the number of depots established are shown in Table 13 for biomass prices ranging from $50 to $70/bdt. Independent depots were infeasible and not established within the model until the offered price at all locations (bio-refineries and depots) reached $55/bdt for biomass traveling directly from the forest. The bio-refinery, in contrast, was able to receive biomass starting at an offered price of $50/bdt. The difference is in the establishment and operating costs associated with the depots, even at the lowest cost level modeled here. No biomass from federal land was considered in this analysis.

Table 13. Establishment of depots with various biomass prices.

	Price of biomass ($/bdt)				
	$50	$55	$60	$65	$70
Number of Depots Established 2005-2020	0	28	33	36	35
Biomass Shipped to Springfield (avg annual bdt)	41,696	217,118	231,935	293,160	363,684
Biomass Shipped to Springfield without Depots	41,696	254,358	478,127	740,029	1,038,863

In the absence of minimum delivery constraints to any modeled facility, the presence of depots affects the amount of biomass shipped directly to Springfield as depots compete with the bio-refinery for raw material. The market price required to deliver roughly 750,000 bdt to a bio-refinery in Springfield was more than $65 without depots, while the market price required for depot operations to overcome the minimum establishment and operating costs was $55. Above a price of $60, there is little increase in the number of established depots; this indicates that some locations are simply economically infeasible. Prices of $55 - $65/bdt are higher than what is currently paid in the biomass market, where estimated prices for raw woods biomass are roughly $35-$45/bdt. The highest quality chip product, chips delivered for pulp and paper use, currently are purchased for approximately $90/bdt (Random Lengths Publications, Inc 2014). The product modeled within RMTSET is a higher quality product than the raw biomass currently being purchased, however, and is likely to be worth more at either a bio-refinery or depot facility; a reasonable price would lie between the current raw biomass price and the pulp chip price. Given these current prices and the results above, a price of $60/bdt was used in all remaining simulations as the price paid for the modeled biomass travelling directly from the woods to the gate at both a bio-refinery and depots. This price is intermediate between current prices for a lower and higher quality product, is near the level that would be required for the bio-refinery to receive the minimum necessary amount, and is sufficiently high to generate depot establishments and allow the exploration of policy implications. Maintaining the market price for biomass at one level allowed for scenarios to isolate the effects of changes in policy or changes in operating costs with equivalent market conditions, in order to conduct sensitivity analyses of these research questions.

6.3.2 Maximum Costs for Establishment of Depots

Estimates of operating and establishment costs for the best case cost estimates and the simplest independent depot (a transshipment depot) were about $15/bdt of capacity to establish (at a 50,000 bdt capacity) and up to $11/bdt to operate (Table 10, page 100). To explore thresholds in feasible establishment and operating costs for depots and to develop parameter combinations for the remaining scenarios, RMTSET with extensions was run for combinations of $1, $5, $10, and $15/bdt for establishment costs and $2, $4, $6, and $8/bdt for operating costs (all without federal sources of biomass). The range of establishment costs considered covers a fully subsidized cost to the more realistic cost, while the range of operating costs explores cost options centered around an estimate half that of the maximum. Considering subsidized establishment costs for depots is realistic, as there have recently been grants and programs that can contribute one-time funds to investors seeking to increase renewable fuel use, ensure local rural mill operation, and/or motivate forest restoration work – all potential reasons to establish feasible depots. It is unlikely, however, that long-term subsidies would be available to fund continued operation, unless we consider market solutions such renewable credit sales. The price to establish and operate depots may differ in the future, regardless of subsidies. These are emerging technologies, and costs may decrease in the future. Here, the interest was in a sensitivity analysis of depot feasibility to levels of establishment and operating costs. Many of these combinations considered yielded no independent depots established (Table 14).

Table 14. Number of independent depots established at varying costs.

Establishment Cost ($/bdt of capacity)	Operating Costs ($/bdt of input biomass) $2	$4	$6	$8
$1	33	26	6	0
$5	24	10	0	0
$10	16	0	0	0
$15	3	0	0	0

This sensitivity analysis indicates that independent depot establishment was less sensitive to changes in establishment cost, in general, than operating costs. Large increases in establishment cost generally had less influence on the number of feasible depots than small increases in the operating cost. This is not surprising, as the establishment cost was charged per capacity unit only once, at the time of establishment, while the operating cost was charged per unit of material arriving at the depot; one dollar increase of operating cost per unit processed has a larger influence on total costs over the life of the depot than one dollar of increased establishment cost. The number of depots established reported here includes only those independent depots established during the policy analysis horizon (prior to 2025). Because the establishment date of any depot was allowed to vary, along with the level of capacity during any period, depots started or increased in size at differing times. Based on the results here, further scenarios in this and remaining sections were run for representative low, medium low, medium, and high cost parameters, corresponding to the sets $1/$2, $5/$4, $10/$2, and $15/$2 in establishment and operating cost amounts, respectively. These combinations cover a range of potential establishment costs with low operating costs and also consider one scenario with a more realistic operating cost ($4/bdt). The locations of established depots also changed as cost parameters changed (Table 15). Twenty-two of the 65 possible locations were never selected for depot establishment.

Table 15. Locations of independent depots under varying cost parameters.

	Establishment/Operating Costs ($/bdt)						
Location	$1/$2	$1/$4	$1/$6	$5/$2	$5/$4	$10/$2	$15/$2
Ashland	--	Yes	--	--	--	--	--
Astoria	Yes	Yes	--	Yes	Yes	Yes	--
Bandon	Yes	Yes	--	Yes	--	--	--
Blue River	Yes	--	--	--	--	--	--
Brookings	--	Yes	--	Yes	--	--	--
Cascadia	Yes	Yes	Yes	Yes	--	--	--
Cave Junction	Yes	--	--	--	--	--	--
Central Point	--	--	--	--	--	Yes	--
Clatskanie	Yes	Yes	--	Yes	--	--	--
Coos Bay	Yes	--	--	--	Yes	Yes	--
Coquille	Yes	Yes	--	--	--	--	--
Cottage Grove	Yes	--	--	--	--	--	--
Dallas	--	--	--	Yes	--	--	--
Dillard	--	--	--	Yes	--	--	--
Estacada	Yes	--	--	Yes	--	--	--
Gale Creek	Yes	Yes	--	Yes	Yes	Yes	--
Garibaldi	Yes	Yes	--	Yes	--	Yes	--
Gaston	Yes	--	--	--	--	--	--
Glendale	--	Yes	--	--	--	--	--
Glide	Yes	--	--	--	--	--	--
Grand Ronde	Yes	Yes	--	Yes	--	Yes	--
Lebanon	Yes	--	--	--	--	--	--
Lyons	--	Yes	--	--	--	--	--
Mapleton	Yes	--	--	Yes	--	--	--
Mill City	Yes	--	--	--	Yes	Yes	Yes
Mist	Yes	Yes	--	Yes	--	--	Yes
Molalla	Yes	Yes	--	Yes	--	Yes	--
Norway	--	--	Yes	--	--	--	--
Noti	Yes	--	--	--	--	--	--
Philomath	Yes	Yes	--	Yes	Yes	Yes	--
Powers	Yes	Yes	--	--	Yes	Yes	--
Reedsport	Yes	Yes	--	Yes	--	--	--

Table 15 con't. Locations of independent depots under varying cost parameters.

	Establishment/Operating Costs ($/bdt)						
Location	$1/$2	$1/$4	$1/$6	$5/$2	$5/$4	$10/$2	$15/$2
Riddle	Yes	Yes	--	Yes	--	Yes	--
St. Helens	--	Yes	--	--	--	--	--
Siletz	Yes	Yes	--	Yes	--	Yes	--
Sutherlin	Yes	Yes	Yes	Yes	Yes	Yes	--
Tillamook	Yes	Yes	--	Yes	Yes	Yes	Yes
Toledo	Yes	Yes	Yes	--	Yes	--	--
Vernonia	Yes	Yes	Yes	Yes	Yes	Yes	--
Warrenton	Yes	Yes	--	Yes	--	Yes	--
White City	Yes	--	--	--	--	--	--
Willamina	Yes	Yes	--	--	--	--	--
Winchester	--	--	--	Yes	--	--	--
Wolf Creek	--	--	Yes	Yes	--	--	--
Number of Depots	33	26	6	24	10	16	3

6.3.3 Locations of Depots without Federal Land Biomass Supply

The number of independent depots selected for establishment varied with differing cost assumptions, as discussed above. The spatial extent and location of established independent depots also varied across the region under the low, medium-low, medium, and high cost assumptions. The depots opened under each cost parameter set are mapped in Figure 9, 10, 11, and 12, respectively. In each map, a red X displays potential depot locations not selected and only depots that opened prior to the 2025 period are mapped and labeled; however, the maximum capacity over the entire modeling horizon is displayed for each depot, regardless of what period that maximum capacity was reached. These results do not include biomass sourced from federal lands, in keeping with a scenario where the gathering of renewable energy credits was desired or required.

Under the lowest cost conditions ($1 per establishment capacity and $2 per processed bdt), 33 depots opened before 2025 (Figure 9). Establishment dates within the analysis horizon (2005 – 2025) varied. Twenty-one depots operated at full capacity at some point in time over the modeling horizon (75,000 bdt/yr), two at medium capacity (50,000 bdt/yr), and ten at low capacity (25,000 bdt/yr). The presence of clusters of high capacity depots indicates high levels of timber harvest and can be seen in the northwest and southwest areas of the region; scattered high capacity depots also were established along the west side of the Cascades and the southern portion of the state.

Under medium-low cost conditions ($5/bdt for establishment costs and $4/bdt for operating costs), significantly fewer independent depots opened (Figure 10). Again, the increase in operating cost had greater effect than increases in establishment cost on limiting depot establishment. Three operated at the highest capacity and the remaining seven at the lowest capacity level. High-capacity depots were clustered in the northwest region of the state. Of the remaining depots, one was also in the northwest, two in the central coast, and three in the south-central part of the state. Only one opened on the eastern side of the Willamette Valley. These medium-low costs mimic most closely a scenario with realistic operating costs for a transshipment depot and a subsidized establishment cost, perhaps through grants or state programs designed to improve renewable energy infrastructure and use.

With medium costs ($10/bdt for establishment and $2/bdt for operating), 16 depots open overall (Figure 11). Four of the five high capacity depots open in the northwest part of the region. No medium capacity depots were opened at all. The highest cost scenario modeled results in only three feasible independent depots: two in the northwest and one along the central Cascades (Figure 12). All of the depots operated at the lowest capacity. The costs at this level were prohibitive for most depot locations.

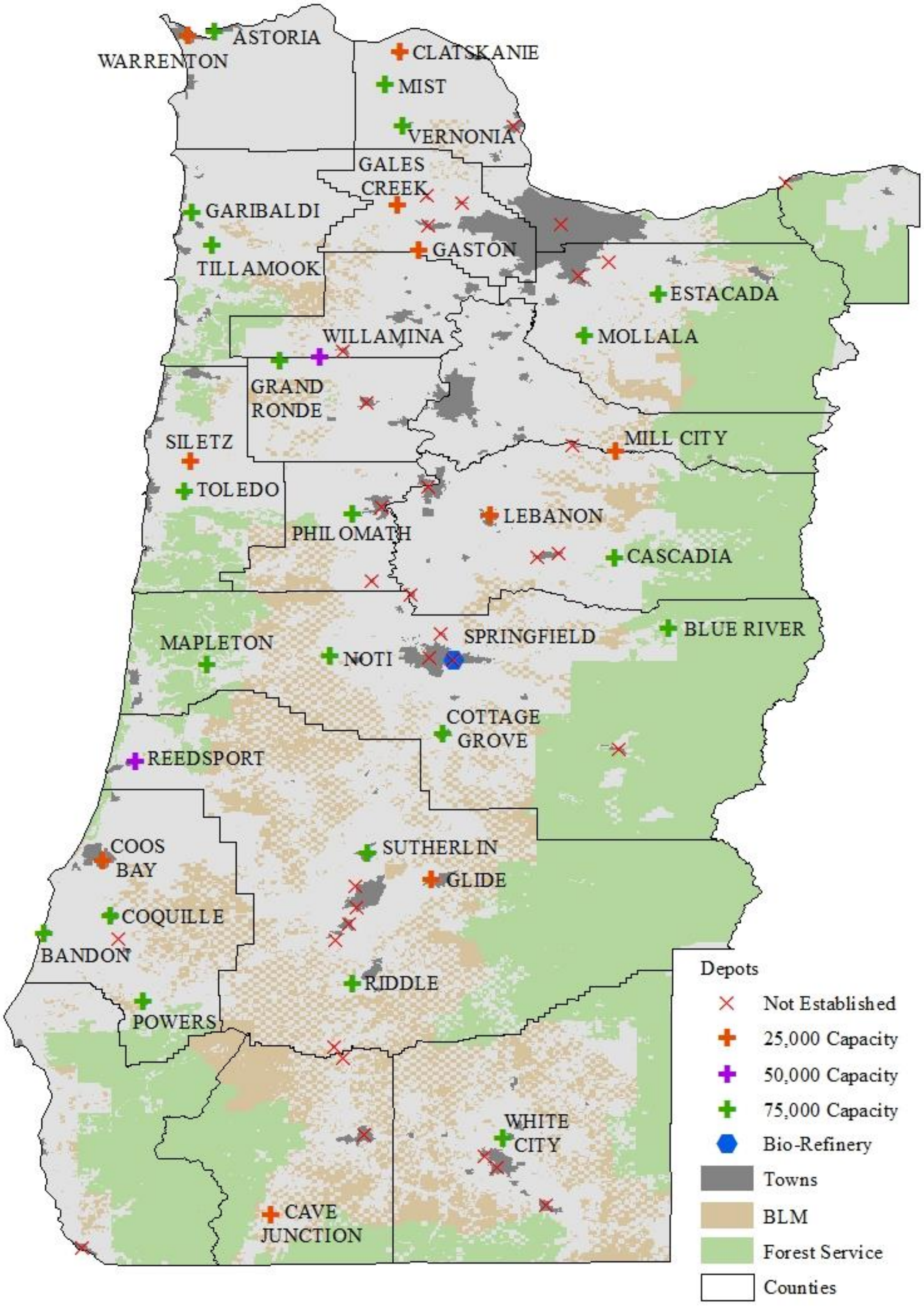

Figure 9. Depots: low costs and no federal biomass supply.

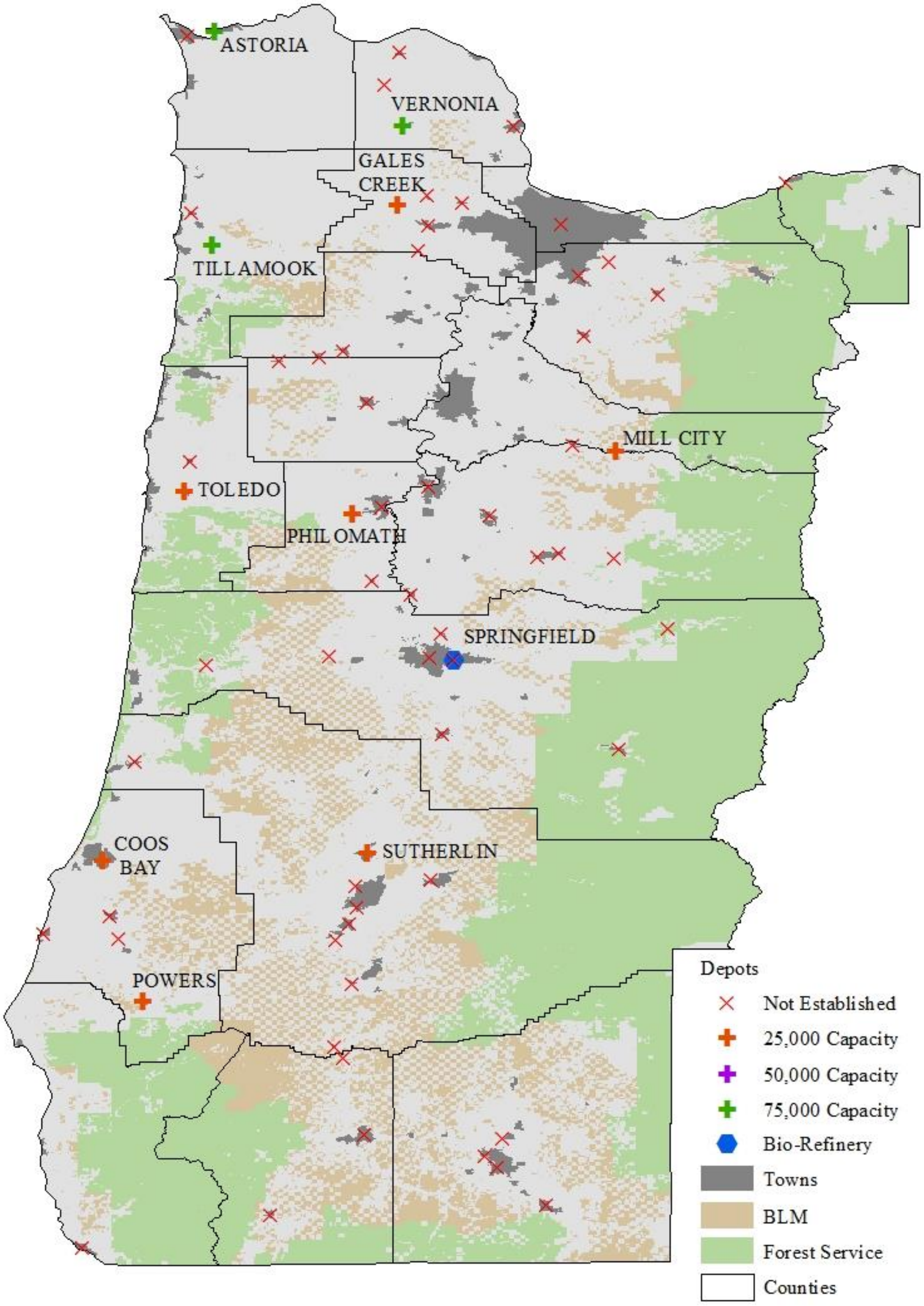

Figure 10. Depots: medium-low costs and no federal biomass supply.

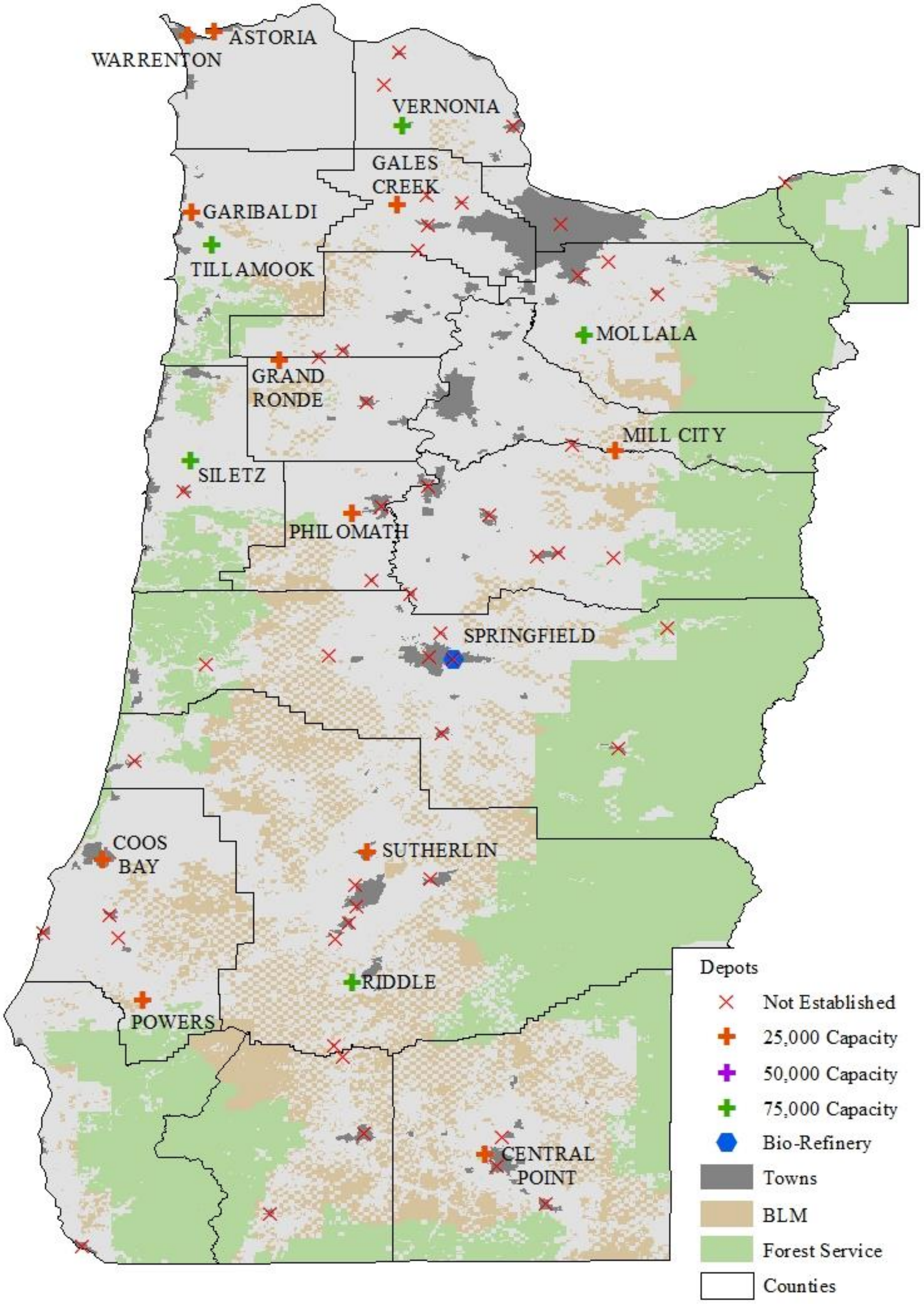

Figure 11. Depots: medium costs and no federal biomass supply.

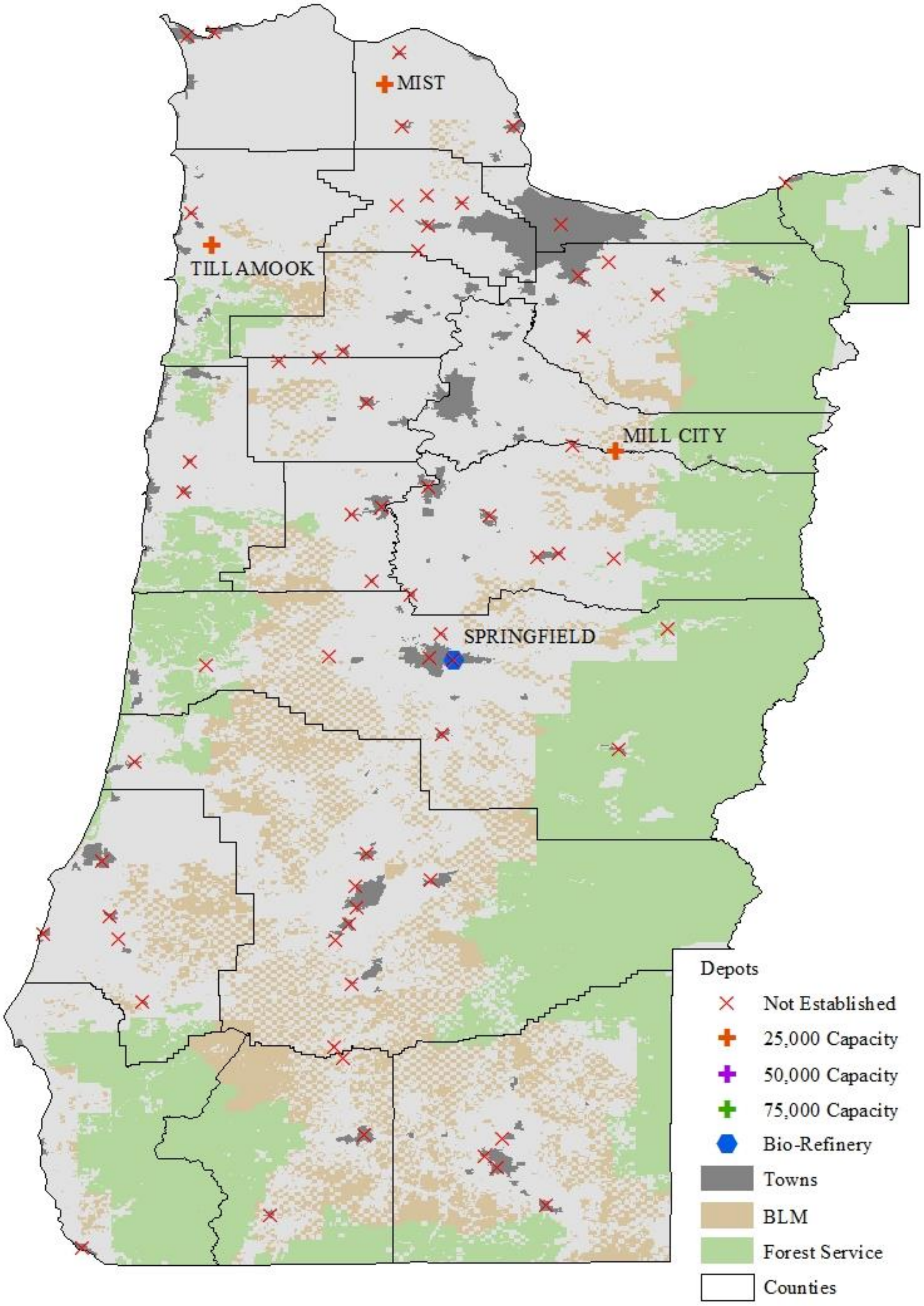

Figure 12. Depots: high costs and no federal biomass supply.

6.4 Independent Depot Locations with Current and Increased Federal Harvest

How would the numbers and locations of established independent depots change if federal harvest was either eligible for renewable fuel credits, or if the end use of the biomass material was not dependent on the sale of RINs as part of the profitability? The latter is possible if depots are gathering and processing biomass for independent local or small-scale use, such as institutional boilers for heat or locally used power. There is harvest occurring on public lands that could provide biomass harvest residues in the process, and this material may be closer to locations most in need of rural development – those very small towns that had been dependent on federal timber for supply material for mills.

The amount of harvest on public lands is far below historical highs and has also failed to reach the levels allowed in the Northwest Forest Plan. Still, the amount of current harvest represents a base case scenario that isolates the effect of incorporating federal land biomass into feedstock streams for any facility. To assess the effects of increases in federal timber harvest, scenarios also include a harvest level of one-and-a-half that of current levels, and twice that of current levels. Two times current levels is closer to what was originally allocated within the Northwest Forest Plan. Modeling increases within RMTSET was done with a simple multiplier conversion. RMTSET allocates a set amount of harvest per county to public lands within the county based on average recent actual harvested amounts; the multiplier file adjusts the amount of harvest allocated in any given period by the designated factor. The distribution of harvested acres within the model, and the budget-minimization manner in which that is done, remained the same.

6.4.1 Locations with Current Federal Harvest Levels

These scenarios assumed current harvest levels and the inclusion of public land-sourced biomass in any process, at either the bio-refinery or the depots. The specific locations given the four cost assumptions (low, medium-low, medium and high) used before are detailed in Table 16 and mapped in Figure 13, 14, 15, and 16.

Table 16. Locations of Depots with Current Public Harvest Levels

	Establishment/Operating Costs ($/bdt)			
Location	$1/$2	$5/$4	$10/$2	$15/$2
Ashland	--	Yes	--	--
Astoria	Yes	Yes	Yes	--
Bandon	Yes	--	Yes	--
Blue River	Yes	--	--	--
Cave Junction	Yes	--	--	--
Clatskanie	Yes	Yes	--	--
Coos Bay	Yes	Yes	Yes	--
Coquille	Yes	--	--	--
Cottage Grove	Yes	--	--	--
Dallas	--	--	Yes	--
Dillard	--	--	Yes	--
Estacada	Yes	--	--	--
Foster	Yes	--	--	--
Gales Creek	Yes	Yes	--	--
Garibaldi	Yes	--	--	--
Gaston	--	--	Yes	--
Glendale	Yes	--	Yes	--
Glide	Yes	--	--	--
Grand Ronde	Yes	--	--	Yes
Lebanon	Yes	--	--	--
Mapleton	Yes	--	--	--
Mill City	Yes	Yes	Yes	Yes
Mist	Yes	--	Yes	Yes
Molalla	Yes	--	Yes	--
Monroe	Yes	--	--	--
Norway	--	--	--	Yes

Table 16 con't. Locations of depots with current harvest levels

	Establishment/Operating Costs ($/bdt)			
Location	$1/$2	$5/$4	$10/$2	$15/$2
Noti	Yes	--	--	--
Philomath	Yes	Yes	Yes	--
Powers	Yes	Yes	Yes	--
Reedsport	Yes	--	Yes	--
Riddle	Yes	--	Yes	--
St. Helens	--	--	Yes	--
Siletz	Yes	--	Yes	--
Sutherlin	Yes	Yes	--	--
Tillamook	Yes	Yes	Yes	Yes
Toledo	Yes	--	--	Yes
Vernonia	Yes	Yes	Yes	--
Warrenton	Yes	--	--	--
White City	Yes	--	--	--
Willamina	Yes	--	--	--
Number of Depots	34	11	18	6

High-capacity depots were prevalent in the western portion of the region, and also occurred along the front of the Cascades, under low-cost assumptions. Twenty of the 34 established depots were high capacity, two were medium capacity, and the remaining 12 were low capacity (Figure 13). Far fewer depots were established under medium-low cost parameters, and the only high capacity depots occur in the northwest portion of the region (Figure 14). Low capacity depots opened in the southern portion of the state, along the western side, and one along the front of the Cascades. Under medium cost parameters, several depots were added in the south, on the western side, and one on the eastern side of the Willamette Valley (Figure 15). Using the high cost assumptions resulted in only low capacity depots established, with four of the six in the northwest portion of the region, one in the southwest, and one along the western front of the Cascades (Figure 16).

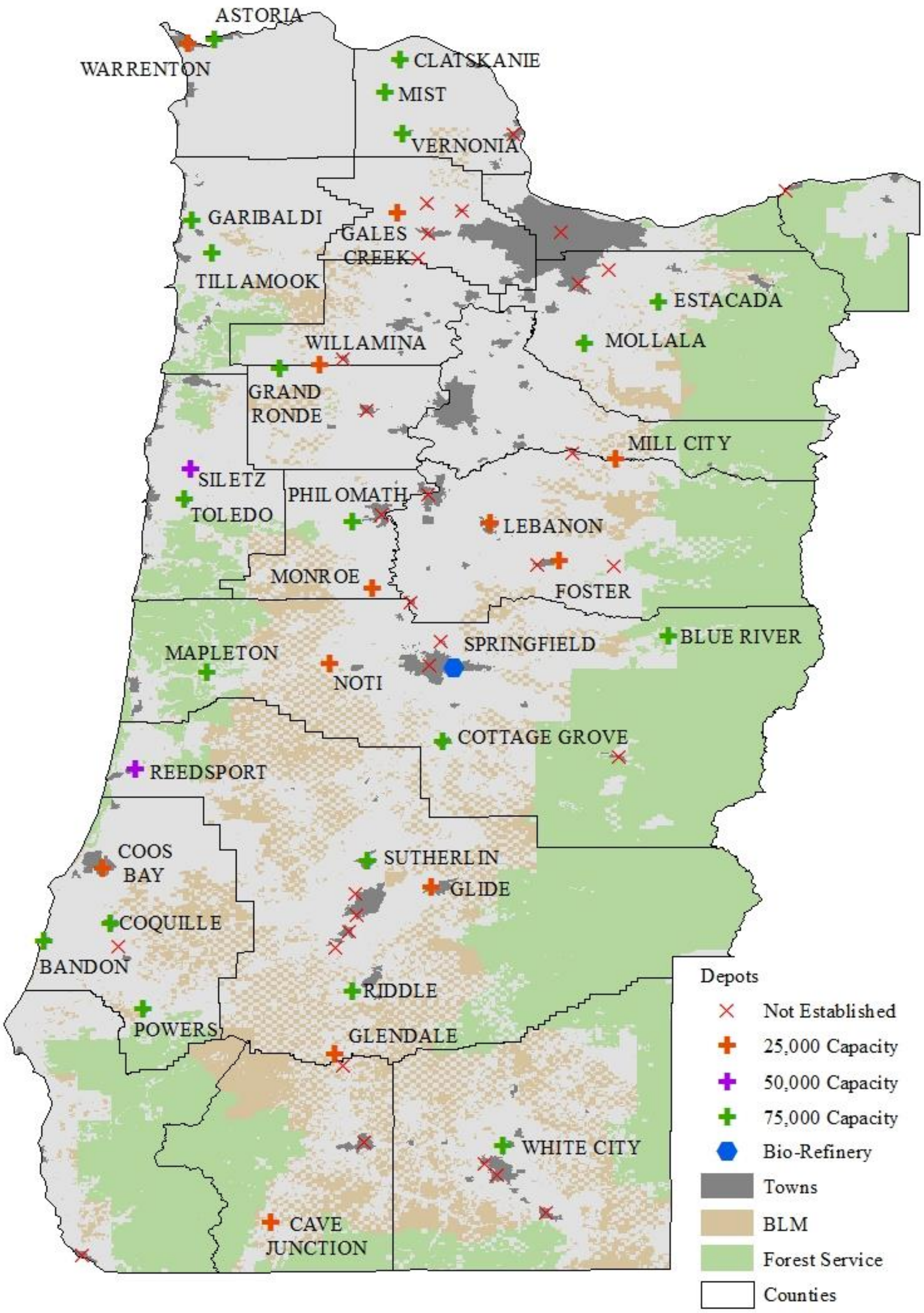

Figure 13. Depots: low cost and current federal harvest levels.

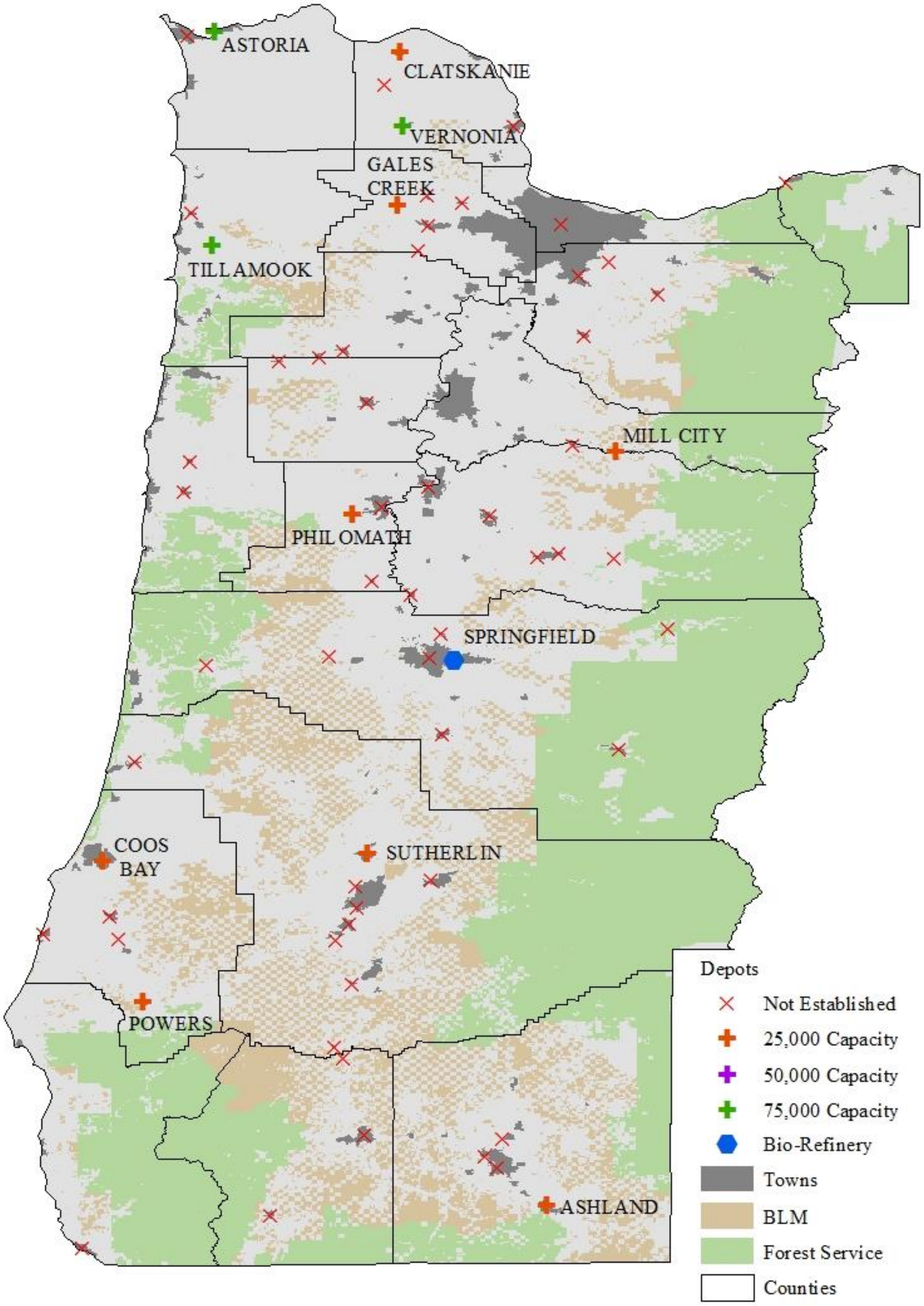

Figure 14. Depots: medium-low costs and current federal harvest levels.

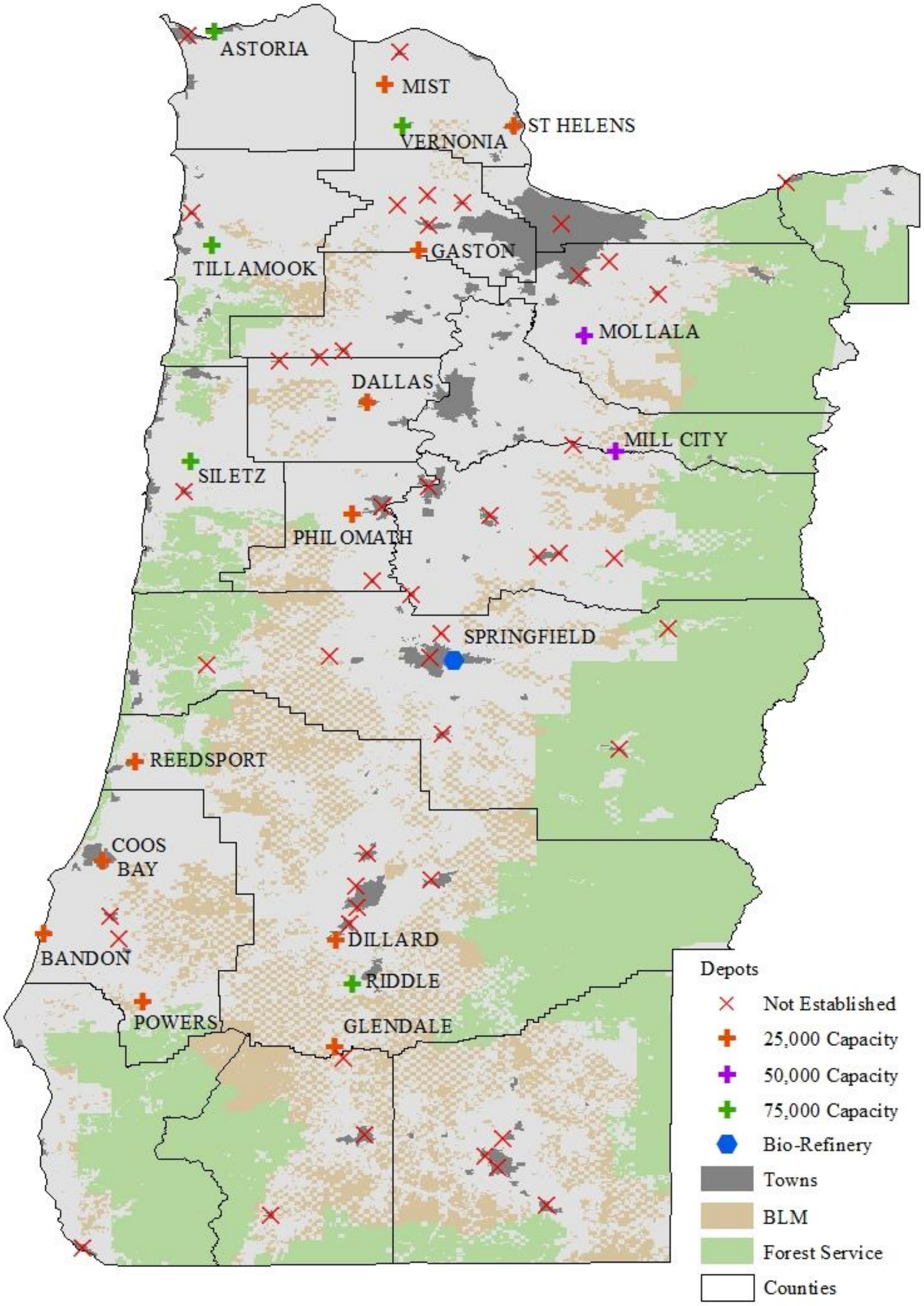

Figure 15. Depots: medium costs and current federal harvest levels.

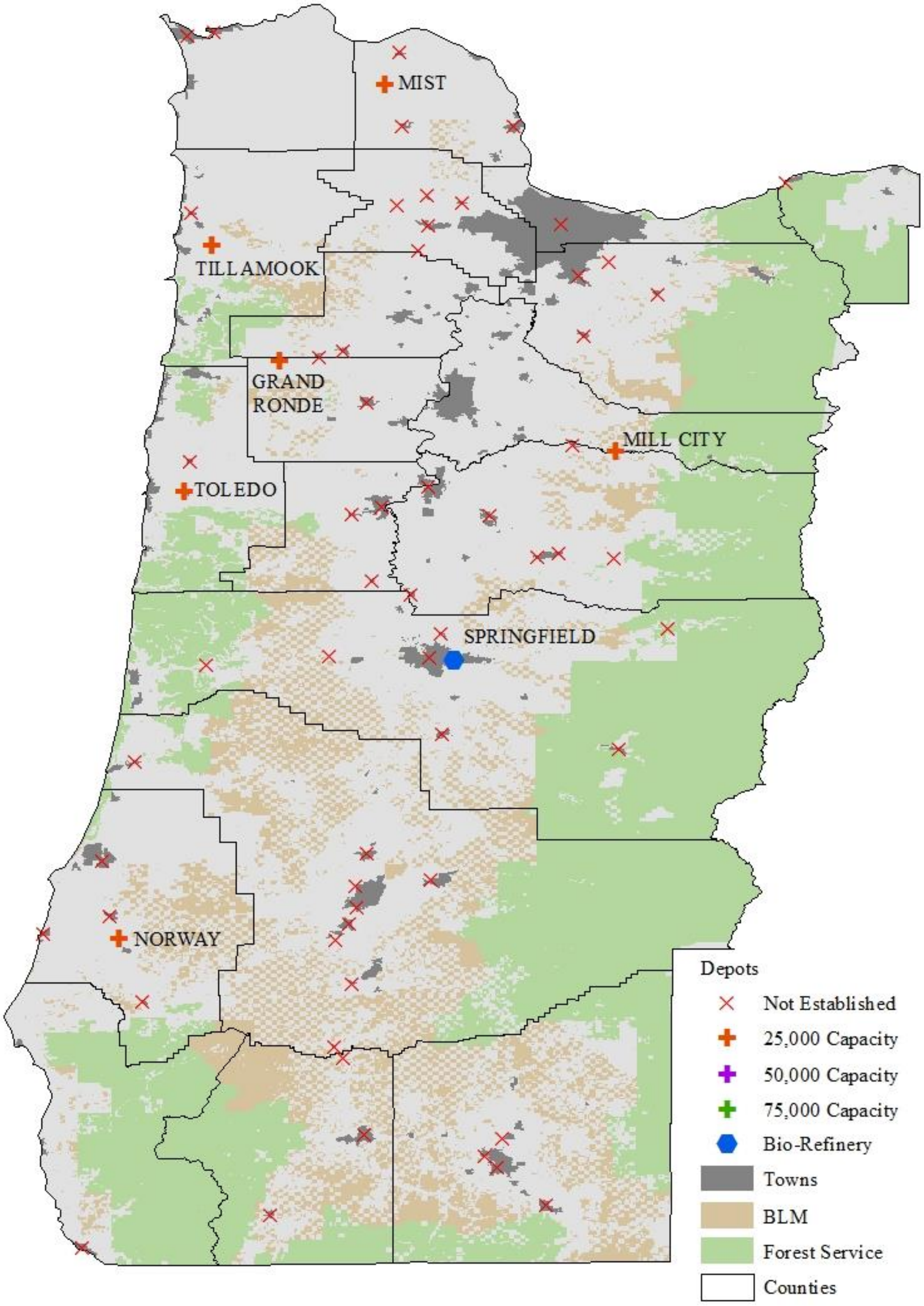

Figure 16. Depots: high costs and current federal harvest levels.

6.4.2 Locations with Increased (1.5x) Federal Harvest Levels

Increasing the harvest level on both U.S. Forest Service and Bureau of Land Management lands by one-and-a-half times resulted in the established depot locations displayed in Table 17 and mapped capacities in Figure 17, 18, 19, and 20 for low, medium-low, medium, and high cost assumptions, respectively.

Table 17. Locations of depots with increased (1.5x) federal harvest

	Establishment/Operating Costs ($/bdt)			
Location	\$1/\$2	\$5/\$4	\$10/\$2	\$15/\$2
Ashland	Yes	Yes	--	--
Astoria	Yes	Yes	Yes	Yes
Bandon	Yes	--	--	--
Banks	--	Yes	--	--
Blue River	Yes	--	--	--
Brookings	Yes	--	--	--
Cascadia	Yes	Yes	Yes	--
Cave Junction	Yes	--	--	--
Central Point	--	--	Yes	--
Clatskanie	Yes	--	--	--
Coos Bay	Yes	Yes	Yes	--
Coquille	Yes	--	--	--
Cottage Grove	Yes	--	--	--
Estacada	Yes	--	--	--
Foster	Yes	--	--	--
Gales Creek	Yes	Yes	Yes	--
Garibaldi	Yes	--	Yes	--
Glide	Yes	--	Yes	--
Grand Ronde	Yes	--	Yes	--
Lebanon	Yes	--	--	--
Mapleton	Yes	--	Yes	--
Mill City	Yes	Yes	Yes	--
Mist	Yes	--	--	--
Molalla	Yes	--	Yes	--
Philomath	Yes	Yes	Yes	--
Powers	Yes	--	--	Yes

Table 17 con't. Locations of depots with increased (1.5x) federal harvest

	Establishment/Operating Costs ($/bdt)			
Location	$1/$2	$5/$4	$10/$2	$15/$2
Reedsport	Yes	--	Yes	--
Riddle	Yes	--	Yes	Yes
St. Helens	--	Yes	--	--
Sheridan	--	--	--	--
Siletz	Yes	--	Yes	--
Sutherlin	Yes	--	Yes	--
Tillamook	Yes	Yes	Yes	--
Toledo	Yes	Yes	--	Yes
Vernonia	Yes	Yes	Yes	--
Warrenton	Yes	--	--	--
White City	Yes	--	--	--
Willamina	Yes	--	Yes	--
Number of Depots	34	12	19	4

Low costs again resulted in high capacity depots scattered throughout the region, and high capacity depots established in relatively close proximity to one another, in the western and northwestern portion of the region (Figure 17). Of the 34 depots established, twenty were high capacity, five were medium capacity, and nine were low capacity. Under medium-low cost assumptions, the increased federal harvest resulted in two high capacity depots in the northwest, and many scattered low capacity depots around the region (Figure 18). Two depots, including the only medium capacity depot, opened along the western side of the Cascades. With medium cost assumptions, seven high capacity depots were scattered throughout the state, as well as twelve low capacity depots (Figure 19). The same two west side Cascades locations were feasible. Under high cost assumptions, even with increased federal harvest, only four low capacity depots opened: two in the south and two in the western portion of the region (Figure 20).

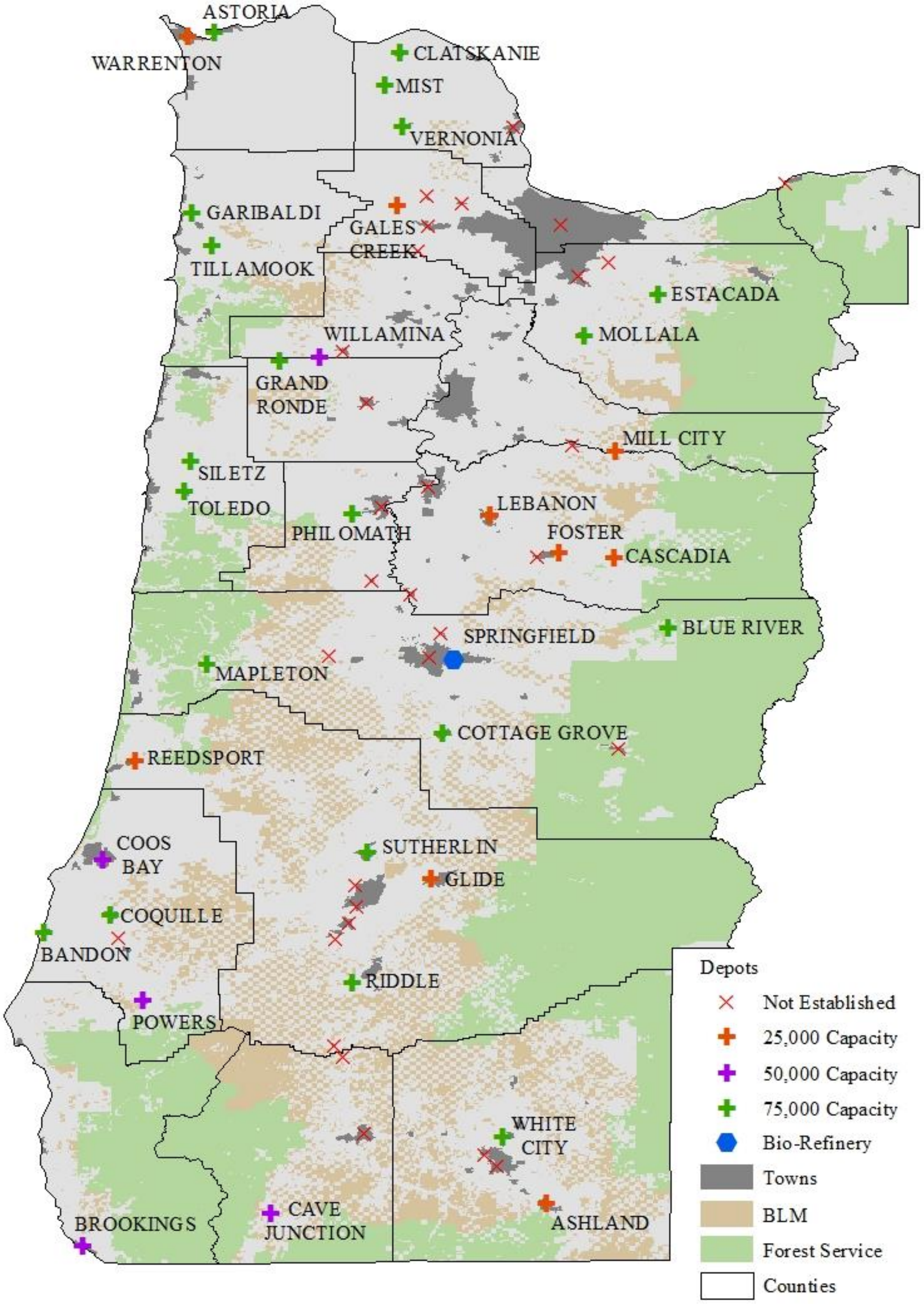

Figure 17. Depots with low costs and increased federal harvest

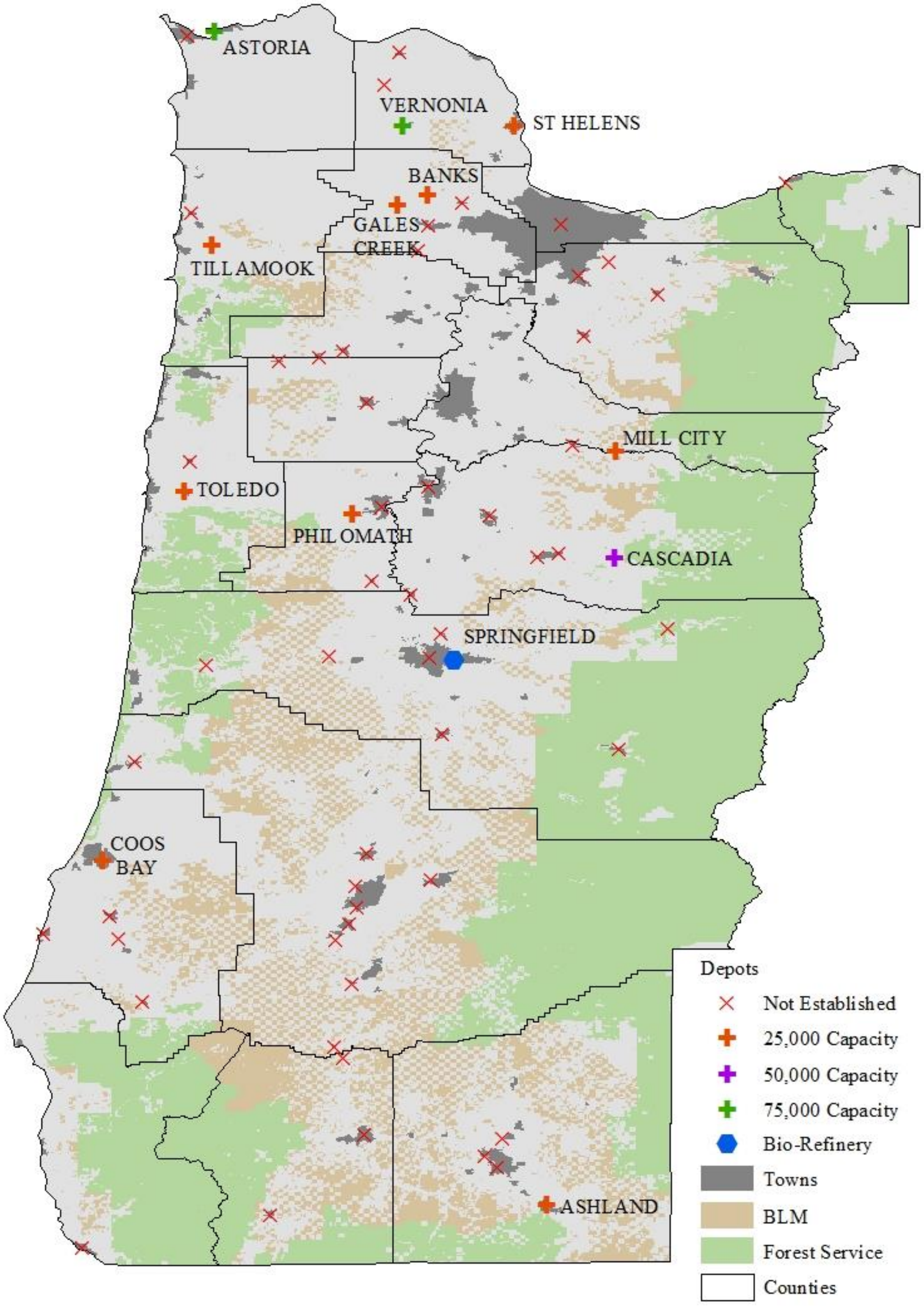

Figure 18. Depots with medium-low costs and increased federal harvest

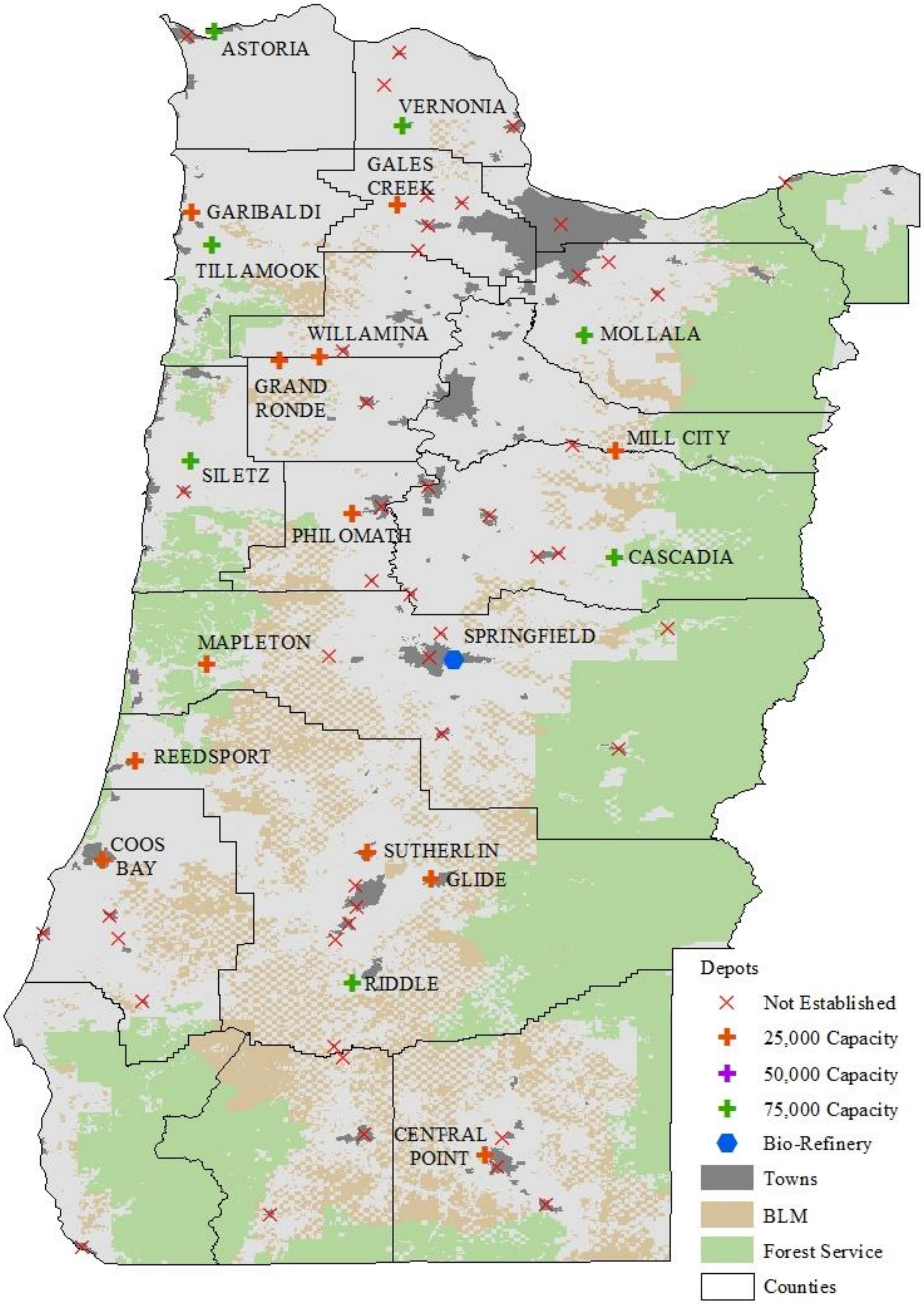

Figure 19. Depots with medium costs and increased federal harvest

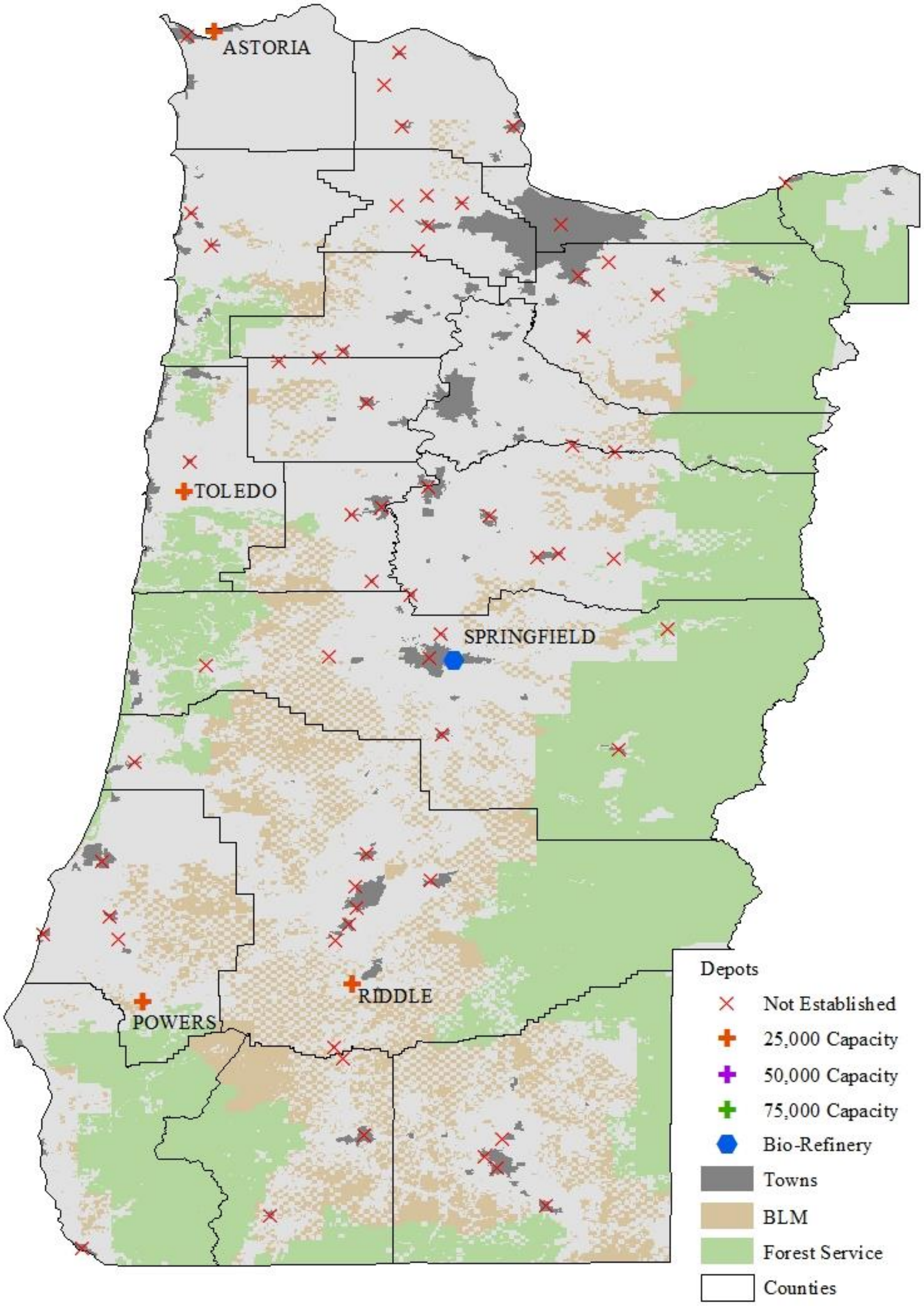

Figure 20. Depots with high costs and increased federal harvest

6.4.3 Locations with Doubled Federal Harvest Levels

Doubled federal harvests mimic a level of harvest more on par with what was allocated within the Northwest Forest Plan. Independent depot location results with this doubled harvest level are listed in Table 18 and the locations and capacities are mapped in Figure 21, 22, 23, and 24 for the same cost parameter sets analyzed previously.

Low cost assumptions resulted in similar results as before: many high capacity depots spread throughout the region, including several along the front of the Cascades (Figure 21). The majority of depots opened were high capacity (19 out of 33); only one was medium capacity. With medium-low costs, out of the nine depots opened, only two northwest locations were high capacity and only one location was medium capacity; only one depot opened along the front of the Cascades (Figure 22). Under medium cost conditions, the majority of the depots (13 out of 15) opened north of Springfield (Figure 23). Three of the depots were medium capacity, all on the western side, while six were high capacity, with all but two in the northwest portion of the region. Finally, given the highest cost assumptions, only one depot was opened: a low capacity depot in Grand Ronde, on the western side, despite the doubling of federal harvests (Figure 24). Reasons for this result are discussed in the next chapter.

Table 18. Locations of depots with doubled federal harvest

	Establishment/Operating Costs ($/bdt)			
Location	$1/$2	$5/$4	$10/$2	$15/$2
Ashland	Yes	Yes	--	--
Astoria	Yes	Yes	Yes	--
Bandon	Yes	--	--	--
Blue River	Yes	--	--	--
Cascadia	Yes	--	Yes	--
Clatskanie	Yes	--	--	--
Coos Bay	Yes	Yes	Yes	--
Coquille	Yes	--	--	--
Cottage Grove	Yes	--	--	--
Estacada	Yes	--	--	--
Gales Creek	Yes	Yes	Yes	--
Garibaldi	Yes	--	Yes	--
Glide	Yes	--	--	--
Grand Ronde	Yes	--	Yes	Yes
Lebanon	Yes	--	--	--
Mapleton	Yes	--	--	--
Mill City	Yes	Yes	Yes	--
Mist	Yes	--	Yes	--
Molalla	Yes	--	Yes	--
Norway	Yes	--	--	--
Philomath	Yes	Yes	Yes	--
Powers	Yes	--	--	--
Reedsport	Yes	--	--	--
Riddle	Yes	--	Yes	--
Roseburg	Yes	--	--	--
Siletz	Yes	--	Yes	--
Sutherlin	Yes	Yes	--	--
Tillamook	Yes	Yes	Yes	--
Toledo	Yes	Yes	Yes	--
Vernonia	Yes	--	Yes	--
Warrenton	Yes	--	--	--
White City	Yes	--	--	--
Willamina	Yes	--	--	--
Number of Depots	33	9	15	1

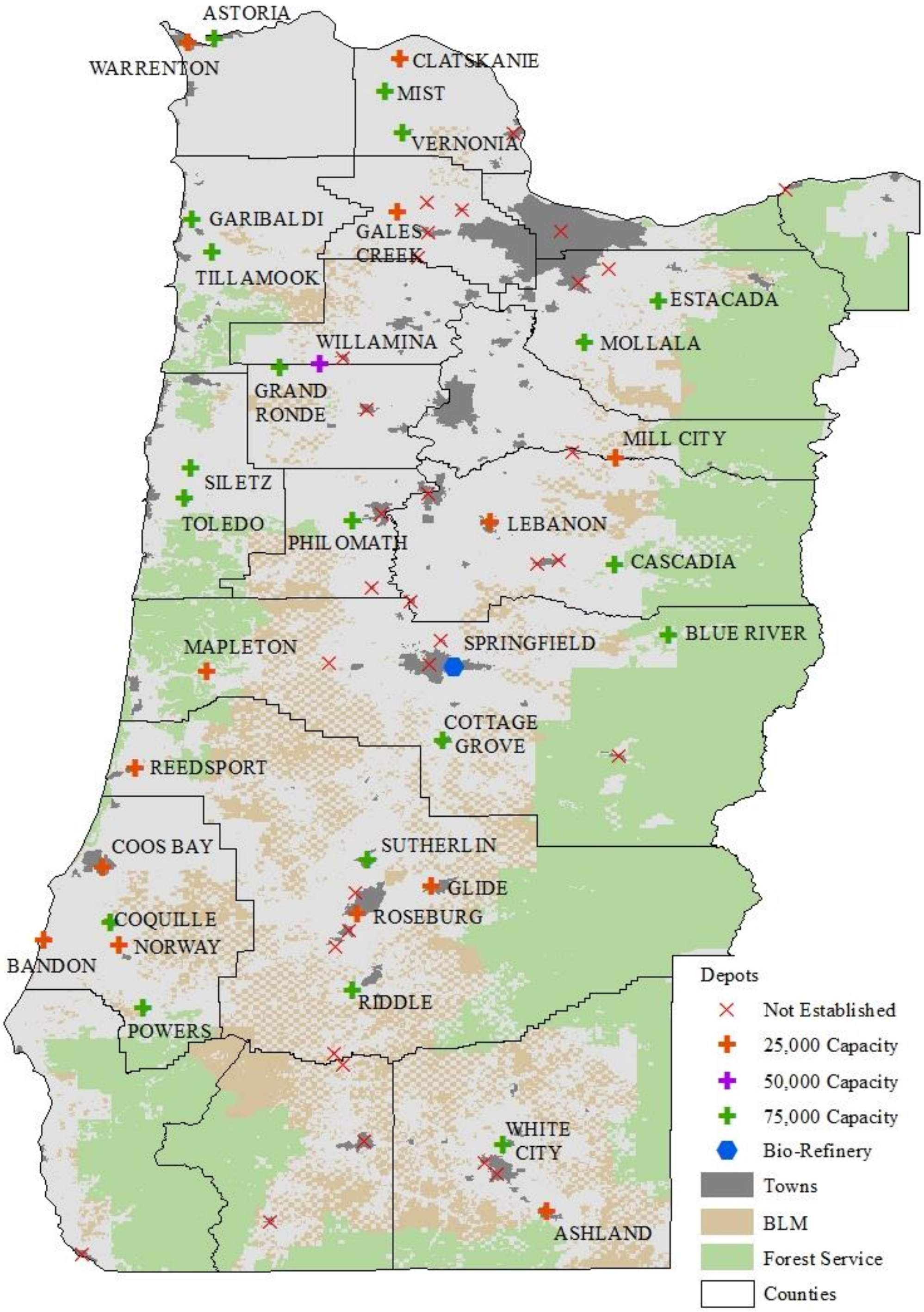

Figure 21. Depots with low costs and doubled federal harvest

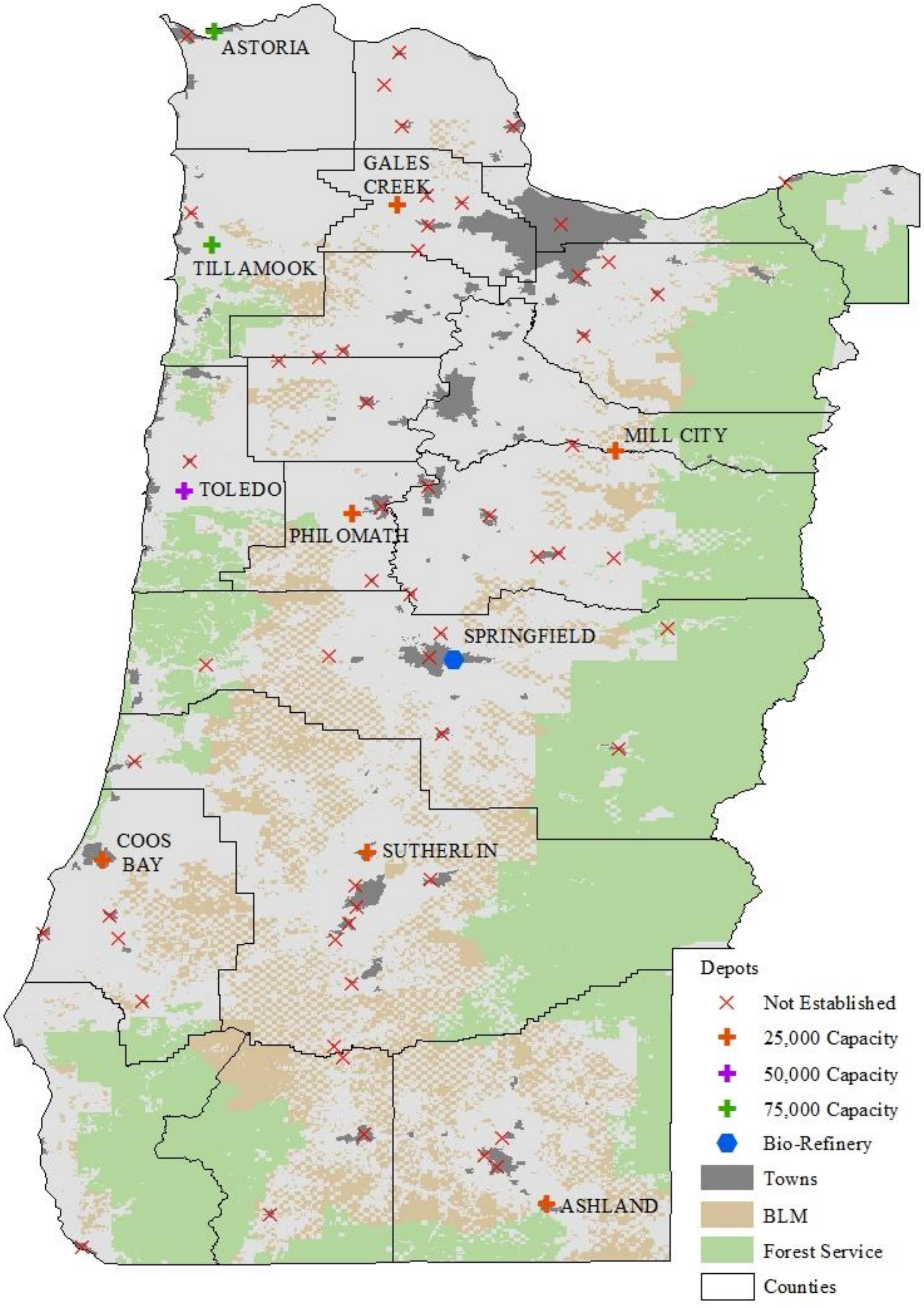

Figure 22. Depots with medium-low costs and doubled federal harvest

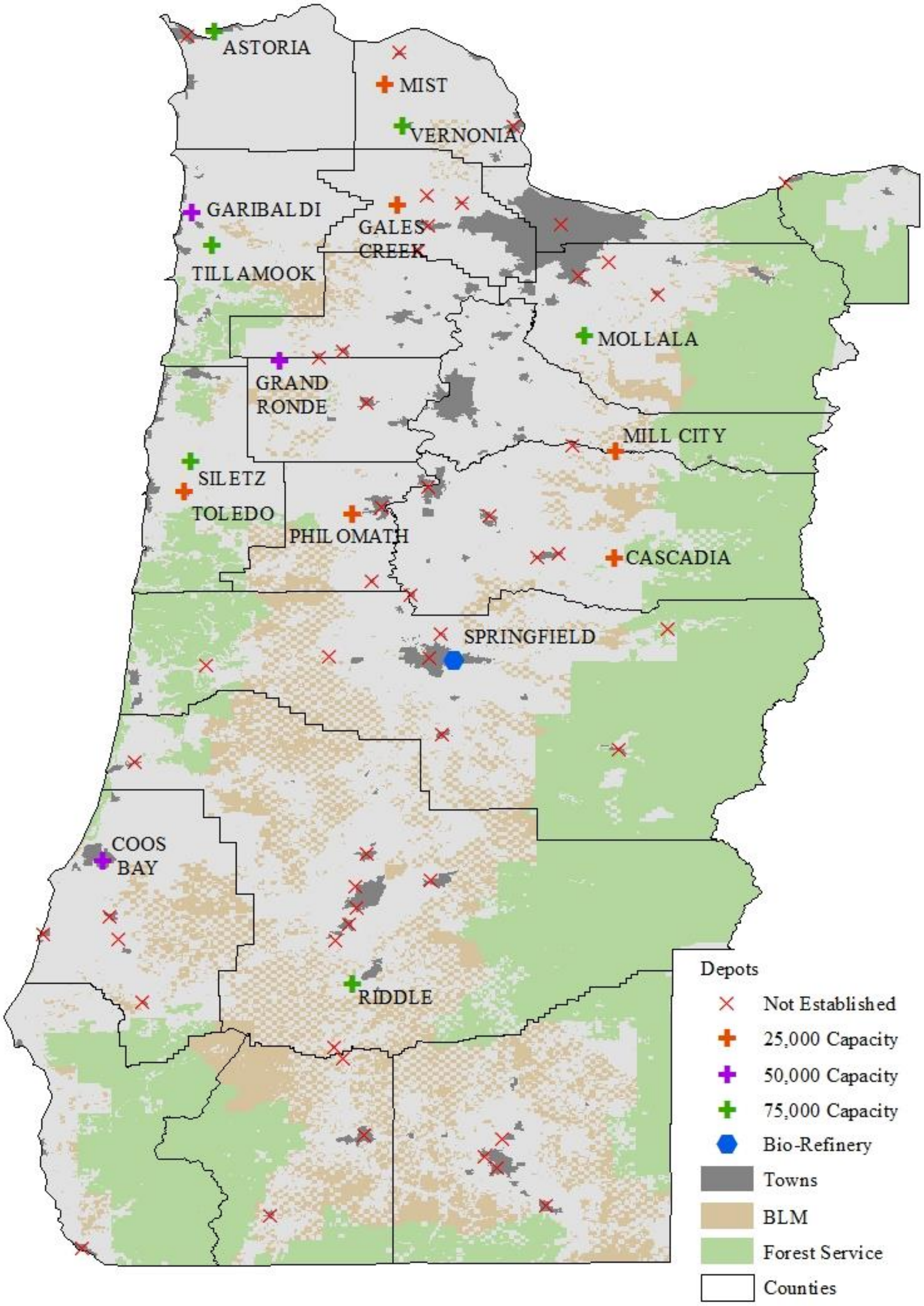

Figure 23. Depots with medium costs and doubled federal harvest

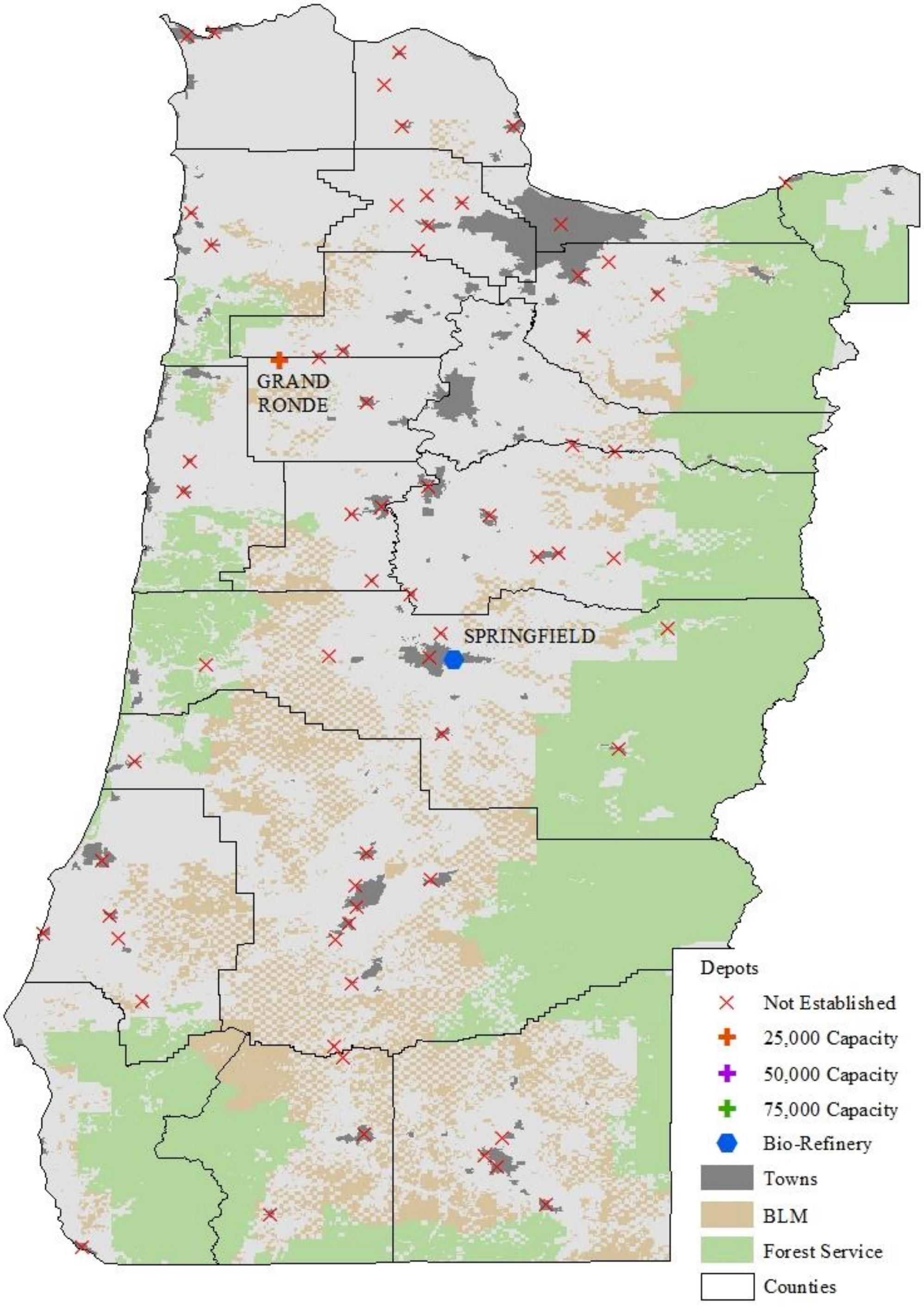

Figure 24. Depots with high costs and doubled federal harvest

6.5 Dependent Depots: The Provision of Refined Biomass to a Bio-refinery

The NARA project has proposed the use of depots as gathering and transfer locations to enhance the cost feasibility of providing biomass to a central bio-refinery. Depots located closer to harvest locations would gather either raw or woods-chipped biomass and transfer the material to high-capacity trucks or rail cars to take advantage of transportation cost savings between depots, which occur in towns and on major roads, and the final bio-refinery destination. RMTSET with extensions can be used to model these bio-refinery dependent depots both directly and indirectly in order to adjust the biomass supply curve at the bio-refinery.

Direct modeling of dependent depots

To directly model the influence of dependent depots on the amount of biomass received at a bio-refinery, RMTSET with extension was adjusted in several ways while still considering the same potential set of depot locations. First, alternative transportation costs between potential depots and the location of the bio-refinery (Springfield) were developed. These transportation costs assumed double trailers of larger capacity able to take advantage of major highways between locations, as well as a drier product being transported between the two locations (a moisture content of 35% as opposed to the direct-from-woods biomass assumption of 50% moisture content). The reduction in moisture content represents either some intermediate drying capacity at the depot, such as that envisioned within the drying station (section 5.2), or some other densification of the product that enabled more material to be shipped in any given trailer. A second product representing this drier material was tracked from depot to bio-refinery within the model and all material passing through the depot was constrained to travel to the bio-refinery. In this model formulation, there is no local use for biomass; all material is gathered and moved to the bio-refinery. The depots exist solely to transfer material to the bio-refinery, and aid the refinery in gathering additional material for a given offered price by capturing cost savings in transportation.

Dependent depots were modeled assuming establishment and operating costs of \$5 and \$4 per bone dry ton, respectively. These cost assumptions most closely align with an operating cost that is feasible and an establishment cost that is subsidized, perhaps with grants or state programs designed to facilitate rural development; the components of costs are listed in Table 10. The same \$60/bdt offered price of biomass was assumed at the bio-refinery. There are two options for modeling the higher quality product within RMTSET. The model maximizes consumer and producer surplus accruing to all agents, so the total benefit to the market of the sale of the material must be represented. To model the higher quality product emerging from the depots, a price differential between the raw biomass at all locations and the refined or processed biomass at the bio-refinery was adjusted upward in \$5 increments.

Given a \$60/bdt price for biomass at the bio-refinery, approximately 478,000 bone dry tons annual average was shipped directly to Springfield. The total surplus from passing biomass through the dependent depot must be greater than the total surplus going directly from the harvest site to the refinery for a dependent depot to be established. A price differential for the material traveling from the dependent depot tot eh bio-refinery represents the higher value material emerging from the depot, and adds to the surplus. The transportation cost savings for this material is also a benefit, and adds to surplus. The sum of these two benefits must exceed the cost of establishing and the discounted operating costs over the life of the depot for the depot to be established. At a $10 or $15 price differential between the product direct from the woods and that coming from the depots, no depots are established (Table 19). With a $20/bdt price differential, depots begin to be established, but only in very near locations. The spread of feasible depots as the price differential grows is mapped in Figure 25. With at least a $20 price differential, depots around Springfield are established (green markers). As the price differential increases to $25/bdt, three depots to the west of Springfield are added, and the location of depots expands both north and south as the price differential increases to $30/bdt. The one exception is Blue River: that depot was only established with a price differential of $20/bdt.

Table 19. Amount of biomass (bdt) shipped to dependent depots and refinery.

	Price differential ($/bdt)				
Depot Location	10	15	20	25	30
Blue River			21,411		
Coburg			97,403	97,403	97,403
Corvallis					26,564
Cottage Grove			97,403	97,403	97,403
Dallas					14,758
Eugene			97,403	97,403	97,403
Harrisburg					56,080
Lebanon					32,468
Mapleton				20,661	50,177
Monroe				97,403	97,403
Noti				64,935	97,403
Philomath					64,935
Springfield	478,127	478,127	210,446	119,342	30,334
Sutherlin					61,983
Sweet Home					32,468
Winchester					11,806
Total	478,127	478,127	524,066	594,550	868,588

The clustering of dependent depots established relatively close to the bio-refinery under the conditions modeled does not necessarily imply that transportation cost savings are greater the nearer the depot is to the bio-refinery – in fact, one would expect that greater distances from the bio-refinery to the depots might result in greater transportation cost savings as the depots consolidate material coming from high-cost forest roads earlier on in the overall transportation of the biomass. The result shown in these simulations may have more to do with the overall geometry of harvest locations, the bio-refinery location, and the dependent depot locations, rather than distance alone. There are many factors involved in the establishment of dependent depots. Transportation cost savings will be greater for depots that are close to transportation routes used for direct delivery of biomass to the bio-refinery, so that total distance is not increased greatly by the diversion of the material through a depot, and for depots where the proportion of total distance between the depot and bio-refinery is relatively large.

Under a dependent depot scenario, it was only optimal to establish a depot with at least a $20/bdt price increase over the $60/bdt base case offered biomass price. Only with a $30/bdt price differential does enough material flow to the bio-refinery to supply a 750,000 bdt/annual facility. With that price differential, almost all the material passed through a depot rather than direct-hauled, as that contributed the most over all possible landowners and activities to the objective function. An additional consideration is that at this price differential, the refined biomass product would be competing with the pulp chip market. Given these cost and price assumptions, establishment of depots to only provide material to a bio-refinery also does little to aid rural communities across the region, instead concentrating the development in one area.

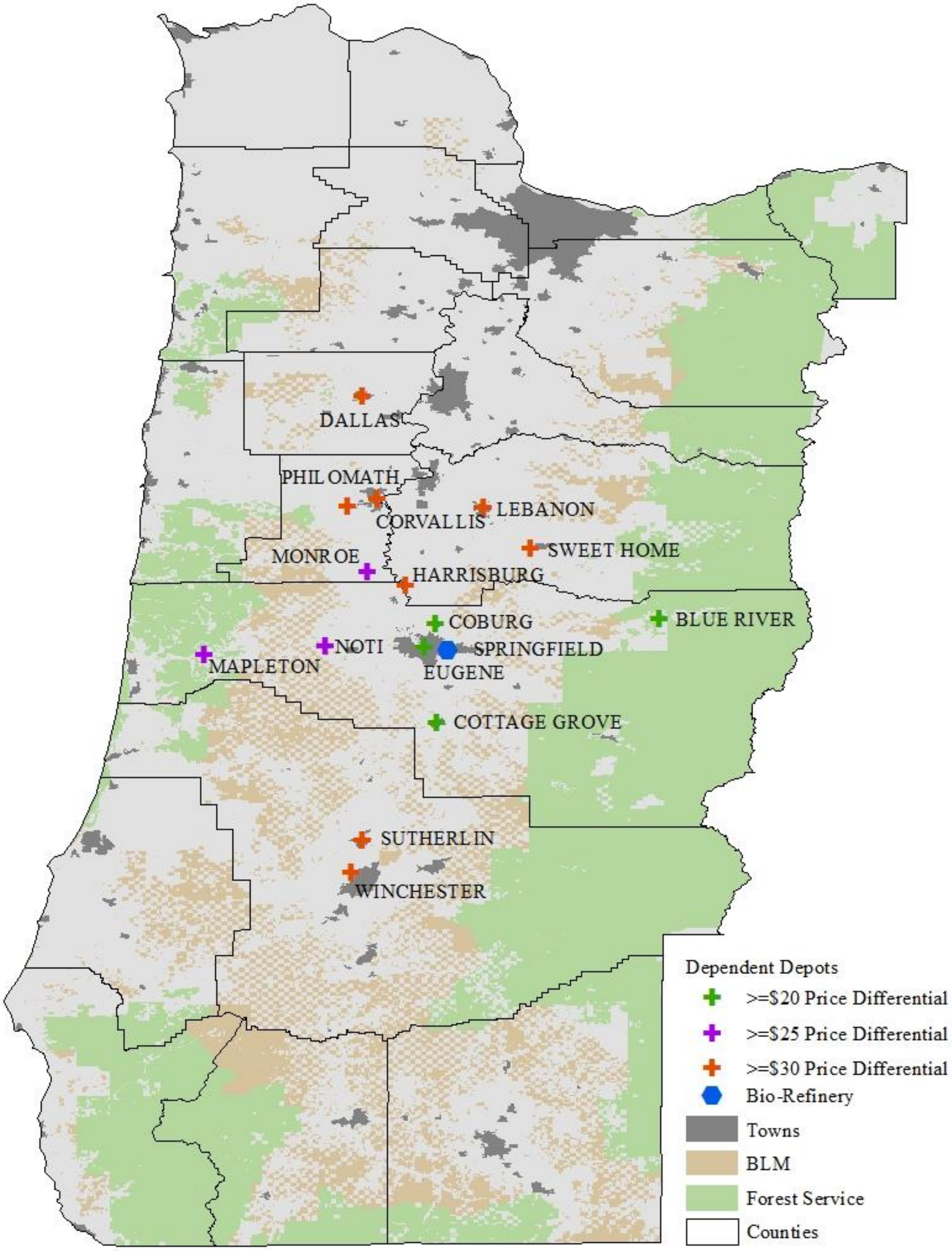

Figure 25. Dependent Depot Locations.

Indirect modeling of dependent depots

Another possible scenario in which depots and the bio-refinery may interact is through depots that are established where it makes stand-alone sense, but the refinery has the option of purchasing additional material from established depots. The cost to the bio-refinery of procuring the necessary amount of biomass in this manner can be inferred from the quantity of material supplied to each depot and the bio-refinery under a given scenario and the transportation cost between the two locations; the refinery would need to pay more than the transport cost between any given depot and the bio-refinery for purchasing processed material to make economic sense.

Using the same cost assumptions of depot establishment from the direct modeling scenario above ($5/bdt establishment cost and $4/bdt operating cost), and assuming no biomass originating from federal lands (given the likely need for the bio-refinery products to qualify as renewable fuels), depots were established in ten locations: Astoria, Coos Bay, Gales Creek, Mill City, Philomath, Powers, Sutherlin, Tillamook, Toledo, and Vernonia (section 6.3.3). Haul costs for each of these locations to Springfield are given in the left-hand column of Table 20. The right-hand column displays the haul costs between depots and Springfield for locations selected as dependent depots in the first analysis within this section under the largest modeled price differential. Independent depots established where it makes economic sense would supply refined material to a bio-refinery that was willing to pay enough per bone dry ton to cover transportation costs. Dependent depot locations were established where the transport cost between the two plus the discounted operating and establishment costs were below the price differential. At a bio-refinery offered price of $30/bdt more than the depot pays for material, only four locations of independent depots could provide material to a bio-refinery in Springfield: Mill City, Philomath, Sutherlin, and Toledo.

Table 20. Haul costs for refined/processed product.

Haul costs between depots and bio-refinery, $/bdt (35% MC)			
Independent Depot locations		Dependent depot locations	
Astoria	56.73	Blue River	18.18
Coos Bay	36.51	Coburg	9.63
Gale Creek	41.25	Corvallis	19.59
Mill City	28.67	Cottage Grove	12.63
Philomath	20.23	Dallas	27.21
Powers	43.58	Eugene	8.50
Sutherlin	23.55	Harrisburg	13.17
Tillamook	43.41	Lebanon	19.13
Toledo	29.37	Mapleton	21.01
Vernonia	46.34	Monroe	14.73
		Noti	13.77
		Philomath	20.23
		Sutherlin	23.55
		Sweet Home	17.76
		Winchester	25.92

Procurement of material from a depot is inefficient relative to the bio-refinery simply offering more per bone dry ton for material delivered directly from the woods. The bio-refinery can attract approximately 478,000 bdt/annually on average at $60/bdt in the absence of depots, leaving a gap of almost 300,000 bdt of necessary feedstock. At $65/bdt, the cost of the feedstock (all of which could be directly supplied to the bio-refinery, at least when considered on an average basis) is $48.75 million dollars. At $60/bdt, the cost of the first 478,000 bdt is $29.22 million, leaving $19.53 million to purchase the necessary 300,000 bdt. Given a cost of at least $80/bdt for this remaining required feedstock – either to cover the haul cost distance of depots established independently, or to cover the price differential necessary to establish dependent depots – the bio-refinery can purchase only 244,125 additional bone dry tons. It is more efficient for the bio-refinery to offer more for each ton of biomass directly from the woods (section 6.2) than for dependent depots to be established and pass material through with these cost assumptions, even given the savings in hauling from depot to bio-refinery. It is unlikely that a bio-refinery would find depot procurement of feedstock optimal relative to direct purchase.

7. Discussion and Conclusion

7.1 The feasibility and Use of Biomass in Western Oregon

Two key questions this work sought to answer are: 1) whether or not emerging technologies and the development of a market for harvest residues has the potential to be used as a rural development tool, and 2) whether or not the inclusion of federal biomass material – either through a policy change that enables biomass sourced from federal lands to be eligible as renewable fuel feedstocks, or through a use of biomass that does not require the sale of RINs to be profitable – has the potential to effect change in rural communities, particularly those that have been most hurt by the downturns in the forest industry. Ideally, a market created for this currently unused material would stimulate relatively stable job creation in rural areas while facilitating forest management. Additionally, I wanted to assess whether or not western Oregon could supply the necessary amount of material for a large-scale facility such as a bio-refinery, and the role that rural intermediate processing centers may play in the feasibility of supplying material. The results show that while western Oregon has plenty of harvest residues as a byproduct of regular market-driven timber harvest, it is costly to process and deliver; a stand-alone bio-refinery would need to offer more than $65 per bone-dry ton to secure the minimum required amount of material. This price is significantly higher than current market prices paid for harvest residue, although within RMTSET, a higher-quality product is modeled. If such a bio-refinery existed, the price offered by the refinery would dominate the market in that area, probably forcing depots to offer the same amount for biomass in order to generate deliveries. It is possible that in locations farther away from the bio-refinery that would not directly compete for material, lower prices could be paid by a depot. Adjusting location-specific pricing is an avenue for future research.

7.1.1 Feasibility of Emerging Technologies as Drivers of Demand

Realistic cost estimates for depots were approximately $15/bdt for establishment cost and just over $4/bdt for operating cost for the best-case scenario of the simplest type of depot that might gather material and utilize it either to ship to the bio-refinery or sell locally; in none of the scenarios considered here did these cost combinations allow for a market-driven establishment of depots in western Oregon. Of the cost parameter sets considered in the various scenarios, the $5/bdt establishment cost along with the $4/bdt operating cost corresponds to the most realistic potential conditions that could generate depot establishment, a situation where grants or subsidies are available to lower the cost of establishing a facility in order to further social goals such as energy independence, un-merchantable material use, and rural development. Unfortunately, in every case the $5/$4 cost set showed the second least number of feasible depots established, second only to the highest cost $15/$2 set, assuming a $60 offered price for biomass at the depot or bio-refinery gates. High operating costs in terms of dollars per bone dry ton of material processed significantly affected the feasibility of depots. Additionally, the modeled $60/bdt price paid for biomass is still well above current market rates. At the current in-woods costs of gathering and processing biomass, along with modeled costs to establish and operate a depot, there is little reason to anticipate wide-spread development of the demand portion of the market required at a local-use, depot level.

While the establishment of a bio-refinery may further energy independence and renewable energy use goals within the region, a bio-refinery demand source alone is unlikely to further rural development goals. The very nature of the bio-refinery infrastructure and contextual needs (e.g., social acceptability) will by necessity locate it in an urban area with (most likely) an active manufacturing base in the forest products industry, transportation advantages, and a large labor force. Since depots did not reduce the cost of the procurement of biomass for a bio-refinery under the scenarios and assumptions analyzed here, a bio-refinery with direct haul of all feedstocks provides minimal benefit to rural communities. While some jobs would be created in the woods in processing and hauling, the potential for expanded rural development would be minimal (specific potential job creation for both in-woods harvesting and processing at the depots is discussed below).

7.1.2 The Role of Increased Supply Material

Over the last twenty years, significant attention has been focused within western Oregon on the role of the decline in federal harvest following the injunction against harvest resulting from the spotted owl crisis in the concurrent decline of rural communities. There is no denying that employment in the logging and wood processing sectors has declined over the last several decades, beginning primarily with the recession of the 1980s. Given the myriad factors at play in the Pacific Northwest forest products industry since then, it is not surprising that debates have raged regarding the relative roles played by technology change, sawlog supply limitations (federal harvest decline), and broader changes in national and international macroeconomies that have shifted labor from manufacturing to service sectors or what the critical factors are for any one particular place, even though from a more general resource economics perspective, market effects dominate timber supply and harvest changes (Adams and Haynes 1989;

Murray and Wear 1998). Debates notwithstanding, the highly publicized and contested injunction laid the stage for the lack of federal supply to be the number one scapegoat in the minds of many residents in rural communities struggling with declining opportunities (Dumont 1996). Post-ante analyses of the effects of the decline in federal harvest on small communities have shown mixed results, giving neither the group advocating for increases in harvest as an answer to rural development issues nor those advocating for less harvest on federal lands reliable evidence to support their proposed fix. Into this current unsettled debate has come the idea of biomass use as a less contentious solution to aid rural communities, particularly those communities surrounded by or near extensive areas of federal land.

Regardless of the role of federal supply in the employment declines in wood processing over the last twenty years, a critical analysis of the role of harvest residue use in aiding rural communities and the potential role that residues from federal harvest may play is essential for forward-looking policy analysis. Market driven biomass use is currently not feasible and is likely to remain that way for some time, barring the development of technology such as a bio-refinery that creates a product so valuable that high prices can be offered for biomass. Even in the case that such a market exists, what is the potential role of federal land in the provision of feedstocks? Alternatively, is there reason to advocate for the inclusion of federal biomass in this market to achieve rural development goals, and is there reason to believe that increased federal harvest will aid the communities most hurt by these changes in the forest products industry?

Using a market model and parameterizing likely technologies within the existing market gives the most realistic answer to these questions. Because actual average levels of federal harvest can be excluded or included in the supply stream, the effects of a policy change can be easily modeled. In addition, the effects of increases in federal harvest were modeled to ascertain what the potential role federal harvest might play. In this discussion the role that increases in federal harvest might play on the continued operation of sawmills in struggling rural communities were not analyzed – only the potential for federal harvest and increased federal harvest to stimulate a biomass market.

In the simplest terms, increasing federal harvest had generally little effect on the number of established depots under the various cost parameters modeled (Table 21). At the lowest cost set, the number of depots varied only between 33 and 34, regardless of the inclusion or level of federal biomass supply. It appears that even given these parameters, certain locations are simply infeasible, regardless of supply source of material.

Table 21. Comparison of number of depots established in the 20-year analysis period

	Establishment/Operating Costs ($/bdt)			
Scenario	$1/$2	$5/$4	$10/$2	$15/$2
No Public Land	33	10	16	3
Public Land, Current Harvest	34	11	18	6
Public Land, Increased (1.5x) Harvest	34	12	19	4
Public Land, Doubled (2x) Harvest	33	9	15	1

For both medium-low and medium cost assumptions, the number of depots established was greatest with increased federal harvest (harvest at one-and-a-half times current levels), although the increase in number of depots established with increased federal harvest over the scenario with no federal supply included was only two and three depots, respectively. The highest cost parameters had the most depots established given the current level of federal supply, although at increased levels the number of depots was still greater than without federal supply. The most interesting result comes when federal harvest is doubled. At the lowest cost, the establishment of depots equals that without federal harvest; in all other cost assumptions, the number of depots declines to the lowest numbers realized within the model. The inclusion of federally sourced material also did not drastically change either the total capacity across the landscape or the capacity levels chosen for depots within the model (Figure 26).

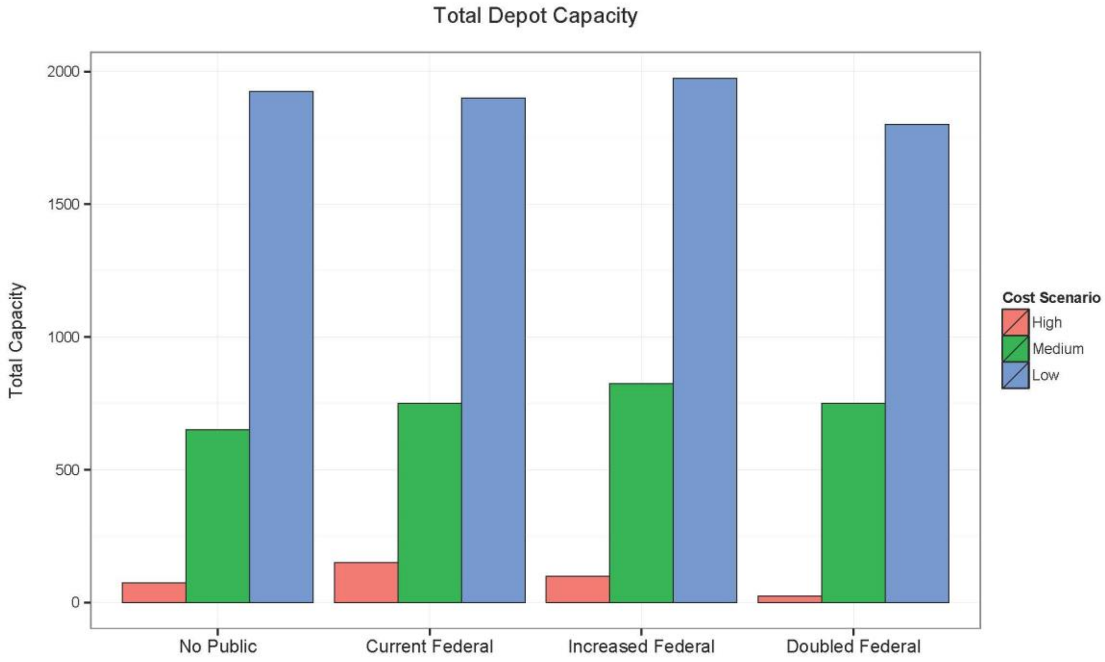

Figure 26. Total depot capacity by federal harvest levels and cost scenario.

This counter-intuitive result arises from the shifting of sawlog harvest within the model between federal and private lands, and the resulting location of the residue generated through the harvest activity. Because it is a market-driven model, RMTSET with extensions uses the current inventory (supply) along with the current price (demand) to optimize harvest decisions across the landscape. Increases in federal harvest result in slightly lower offered prices for sawlogs in the near term and slight decreases in private harvest as the market adjusts, with a resultant shift from private lands to public lands in the source of biomass supply that is a ride-along to harvest; an example of these results under the low cost scenario is given in Table 22 below.

Table 22. Delivered amounts of sawlogs and biomass by source landowner.

Delivered Material by source ownership, low cost scenario, 2005 - 2025

Average Annual Delivered Sawlogs, MBF	USFS	BLM	STATE	PRIVATE	Total
With Current Federal Harvest	69,150	73,566	249,976	2,855,900	3,248,592
With Increased Federal Harvest	103,726	108,078	247,437	2,824,420	3,283,660
With Doubled Federal Harvest	138,301	142,255	244,955	2,799,329	3,324,839

Average Annual Delivered Biomass, BDT	USFS	BLM	STATE	PRIVATE	Total
Without Current Federal Harvest	0	0	119,393	1,558,508	1,677,901
With Current Federal Harvest	38,388	30,063	118,217	1,551,288	1,737,956
With Increased Federal Harvest	48,530	43,589	118,778	1,530,680	1,741,576
With Doubled Federal Harvest	59,268	54,968	113,815	1,459,467	1,687,517

As is evident from the table, the amount of biomass delivered to all locations (depots and bio-refinery) increases slightly over the scenario when no federal supply is included as federal harvest is considered and then increased. It decreases when federal harvest is doubled, even though the overall total delivered sawlog amount rises slightly. The key to understanding this result is in the substitution away from private supply as federal supply is increased. RMTSET is a market model with timber harvest driven by the current price in the sawlog market. As the price-invariant public supply increases, continued harvest on private lands would result in lower market prices for sawlogs. Just as in the actual market, increases in federal harvest without increases in demand result in lower prices offered for sawlogs, a signal to private landowners to defer harvest until prices are more favorable. The market equilibrium price shifts upward again in response to the contraction of private supply and the source of timber shifts slightly to public lands relative to the base line scenario.

This matters for biomass production and delivery. Federal lands differ from private lands in structure and composition of the stands, past management activities, and location. Federal land is not distributed uniformly across the landscape. Because federal lands were largely carved out prior to the early 1900s, more marginal land was allocated to national forests as much of the more desireable land had already been acquired by private timber interests. In general, federal land is more remote, more rugged in terrain, and less productive than private forest land. However, federal stands are also more likely to be overstocked with small, non-merchantable material due to a lack of forest management activities in recent decades. The effects of both the stand composition and the location of the harvested stands as private lands are substituted away from is shown in Table 23. The top section of the table show the amount of on-site biomass available in green tons per thousand board feet (mbf) harvested. The bottom displays the amount of delivered biomass, to either a depot or bio-refinery, in green tons per mbf of harvest. The overstocked nature of the federal lands is clear from the much higher ratio of generated biomass per harvested amount, relative to private lands. As federal harvest increases, the model moves harvest from the older, more accessible (and cheaper to harvest) well-stocked stands to stands further removed. The biomass being produced as a harvest ride-along is moving further away from towns and highways, increasing the transportation cost. This effect is clearly seen in the bottom portion of the table. Delivered biomass per harvested amount stays relatively constant for state and private lands, while declining steadily as harvest levels increase for federal lands. The increase in transportation cost eliminates some depot locations from feasibility.

Table 23. Generation and delivery of biomass by landowner.

Generated GT/MBF	USFS	BLM	STATE	PRIVATE
With Current Federal Harvest	3.4171	0.9021	1.1363	1.2509
With Increased Federal Harvest	2.6099	0.9025	1.1336	1.2452
With Doubled Federal Harvest	2.1826	0.9006	1.1276	1.2416

Delivered GT/MBF	USFS	BLM	STATE	PRIVATE
No Federal Harvest	0	0	0.9549	1.0915
With Current Federal Harvest	1.1103	0.8173	0.9458	1.0864
With Increased Federal Harvest	0.9357	0.8066	0.9601	1.0839
With Doubled Federal Harvest	0.8571	0.7728	0.9293	1.0427

In addition, the declines in private harvest as public harvest increases appears to render some depots that had been previously supported by private biomass material infeasible. The increased federal harvest shifts the placement of depots within the landscape – creating de facto winners and losers in terms of feasible rural development use of this technology. Some of this can be seen by comparing the maps in chapter 6 that show capacities established across the landscape for all cost assumptions and public harvest scenarios.

Locations may be feasible in one scenario and infeasible in others; this does not always occur in a predictable fashion as the federal harvest increases as the model trades off optimal locations for depot establishment given the spatial location of harvest. Locations may also change in the maximum capacity realized at that location as the harvest locations (and amounts) shift.

Table 24 below shows the established capacities across the landscape under the different harvest assumptions for a low cost depot. Some locations are robust to the harvest scenario, and the same capacity depots were established regardless of the level or inclusion of public biomass material (e.g., Astoria, Blue River, Mist). Some locations were only established with increased or doubled federal harvest (e.g. Norway, Roseburg). These cost assumptions lead to the maximum capacity established within any model runs at 1,975/bdt/year of processing capacity under the increased federal harvest scenario.

Table 24. Capacity of established depots with low cost assumptions.

	Maximum capacity of established depots, low cost assumptions			
City	No Public Land Included	Current Federal Harvest Levels	Increased Federal Harvest Levels	Doubled Federal Harvest Levels
Ashland	0	0	25	25
Astoria	75	75	75	75
Bandon	75	75	75	25
Blue River	75	75	75	75
Brookings	0	0	50	0

Table 24 (con’t). Capacity of established depots with low cost assumptions.

Cascadia	75	0	25	75
Cave Junction	25	25	50	0
Clatskanie	25	75	75	25
Coos Bay	25	25	50	25
Coquille	75	75	75	75
Cottage Grove	75	75	75	75
Estacada	75	75	75	75
Foster	0	25	25	0
Gales Creek	25	25	25	25
Garibaldi	75	75	75	75
Gaston	25	0	0	0
Glendale	0	25	0	0
Glide	25	25	25	25
Grand Ronde	75	75	75	75
Lebanon	25	25	25	25
Mapleton	75	75	75	25
Mill City	25	25	25	25
Mist	75	75	75	75
Molalla	75	75	75	75
Monroe	0	25	0	0
Norway	0	0	0	25
Noti	75	25	0	0
Philomath	75	75	75	75
Powers	75	75	50	75
Reedsport	50	50	25	25
Riddle	75	75	75	75
Roseburg	0	0	0	25
Siletz	25	50	75	75
Sutherlin	75	75	75	75
Tillamook	75	75	75	75
Toledo	75	75	75	75
Vernonia	75	75	75	75
Warrenton	25	25	25	25
White City	75	75	75	75
Willamina	50	25	50	50
Average	58.3	55.9	58.1	54.5
Total	1925	1900	1975	1800

The second-fewest depots were established under the medium-low cost scenario, the one that mostly closely mimics a realistic operating cost and a subsidized establishment cost. The locations and capacities for this cost structure are shown in Table 25 below. Several locations were robust with respect to the modeled harvest scenario (Coos Bay, Mill City, Philomath, etc) while several were only established with increased federal harvest. Again, the doubled federal harvest resulted in the lowest overall landscape capacity for this cost structure even as average capacity established was higher than the two other federal land harvest scenarios.

Table 25. Capacity of established depots with medium-low cost assumptions.

	Maximum capacity of established depots, medium-low cost assumptions			
City	No Public Land Included	Current Federal Harvest Levels	Increased Federal Harvest Levels	Doubled Federal Harvest Levels
Ashland	0	25	25	25
Astoria	75	75	75	75
Banks	0	0	25	0
Cascadia	0	0	50	0
Clatskanie	0	25	0	0
Coos Bay	25	25	25	25
Gales Creek	25	25	25	25
Mill City	25	25	25	25
Philomath	25	25	25	25
Powers	25	25	0	0
St. Helens	0	0	25	0
Sutherlin	25	25	0	25
Tillamook	75	75	25	75
Toledo	25	0	25	50
Vernonia	75	75	75	0
Average	40.0	38.6	35.4	38.9
Total	400	425	425	350

The medium cost assumptions were a $10/bdt establishment cost and a $2/bdt operating cost. With these assumptions, the capacity and locations of the established depots are listed in Table 26 for each of the harvest scenarios.

Table 26. Capacity of established depots with medium cost assumptions.

	Maximum capacity of established depots, medium cost assumptions			
City	No Public Land Included	Current Federal Harvest Levels	Increased Federal Harvest Levels	Doubled Federal Harvest Levels
Astoria	25	75	75	75
Bandon	0	25	0	0
Cascadia	0	0	75	25
Central Point	25	0	25	0
Coos Bay	25	25	25	50
Dallas	0	25	0	0
Dillard	0	25	0	0
Gales Creek	25	0	25	25
Garibaldi	25	0	25	50
Gaston	0	25	0	0
Glendale	0	25	0	0
Glide	0	0	25	0
Grand Ronde	25	0	25	50
Mapleton	0	0	25	0
Mill City	25	50	25	25
Mist	0	25	0	25
Molalla	75	50	75	75
Philomath	25	25	25	25
Powers	25	25	0	0
Reedsport	0	25	25	0
Riddle	75	75	75	75
St. Helens	0	25	0	0
Siletz	75	75	75	75
Sutherlin	25	0	25	0
Tillamook	75	75	75	75
Toledo	0	0	0	25

Table 26 (con't). Capacity of established depots with medium cost assumptions.

Vernonia	75	75	75	75
Warrenton	25	0	0	0
Willamina	0	0	25	0
Average	40.6	41.7	43.4	50.0
Total	650	750	825	750

One atypical result of the medium cost assumptions is that the doubled federal harvest level does not, in this case, result in the lowest overall established capacity. The increased federal harvest level does again result in the largest overall established capacity, however.

Capacities by established location with high cost parameters are shown for each harvest scenario in Table 27 below. In no scenario were any depots of medium or high capacity established, and no locations were robust with respect to harvest scenario. Under high cost assumptions, the most extreme decline in the number of established depots (and overall landscape capacity established) was seen with doubled federal harvest.

Table 27. Capacity of established depots with high cost assumptions.

	Maximum capacity of established depots, high cost assumptions			
City	No Public Land Included	Current Federal Harvest Levels	Increased Federal Harvest Levels	Doubled Federal Harvest Levels
Astoria	0	0	25	0
Grand Ronde	0	25	0	25
Mill City	25	25	0	0
Mist	25	25	0	0
Norway	0	25	0	0
Powers	0	0	25	0
Riddle	0	0	25	0
Tillamook	25	25	0	0
Toledo	0	25	25	0
Average	25	25	25	25
Total	75	150	100	25

7.1.3 Effects of a Biomass Market in Specific Places

The results from the biomass supply curve, the depot establishment minimum prices, and the depot establishment and operating costs maximums suggest that the current prices – both in terms of offered price for delivered biomass and in terms of depot costs – are not adequate for these emerging technologies to be a feasible, market-driven rural development tool in and of themselves. Of interest, however, are also the policy implications under circumstances where depots are economically viable, vis-à-vis the most struggling communities. If market conditions improved and the establishment of depots was feasible, where are the locations in western Oregon that are optimal for this type of development?

If the goal is to have a market-driven solution that helps the most struggling communities – those most affected by changes in forest policy – a depot solution of biomass use is not promising at this time. The maps presented in sections 6.3 and 6.4 show that in general, depots are the most feasible in areas of current, high-volume harvest – locations likely to still be supporting active sawmills or other processing facilities. Locations in counties along the north and central coast were frequently chosen. It may be that these are also places in need of rural development, but given their proximity within private industrial timberlands, they are not likely to have felt the dramatic decline that occurred following the spotted owl crisis. Indeed, even when federal land biomass is included, there are depots established only sporadically in the rural communities that have been profiled in the press as representing the fate of the Pacific Northwest timber dependent communities – those lying along the western front of the Cascades, where extensive federal lands are found, and those in the southwestern portion of the state. To discuss the potential for these emerging markets to aid these “poster” towns for the decline of the timber industry, the results from this market model are considered as they pertain to three towns that have been profiled in national press: Sweet Home, Oakridge, and Cave Junction.

Sweet Home, Oregon

Sweet Home, in eastern Linn County, sits near the border of the Willamette National Forest, at one point in time the highest timber producing National Forest. A plywood/veneer mill still operates in nearby Foster, but the number of mills – already trending downward as the nearby private old-growth supply diminished – declined further following the harvest injunction. Sweet Home is also home to a USFS ranger station; as timber sales and income declined at the National Forest level, local federal employment declined as well. In 1991, Sweet Home was profiled in Audubon magazine, in an article titled “Sour Times in Sweet Home: frustration, despair, anger, and political manipulation follow layoffs in a troubled Oregon timber town” (Mitchell 1991). The tone of the article is clear, as are the opinions of those interviewed for it: the lack of federal timber was the source of the town’s decline, and the lack of federal timber was the result of environmental pressures from people from urban (mostly east coast) cities. Given even an optimistic biomass market scenario, however, Sweet Home is not likely to benefit. In no scenario – regardless of cost assumptions or federal harvest assumptions – was Sweet Home an optimal depot location. The only scenario that produced depot establishment in Sweet Home was a dependent depot processing material only for delivery to a bio-refinery under a very high ($30/bdt) price differential for the refined material.

Oakridge, Oregon

Fifteen years later, the fate of previously timber-dependent communities was still making national news, as the New York Times profiled Oakridge, Oregon in an article titled “Rural Oregon Town Feels Pinch of Poverty” (Eckholm 2006). Illustrated with dramatic, depression-era style photographs , the article briefly describes the heyday experienced by residents working in the mills or supported by mill workers and the wages they received in this eastern Lane County community. The last mill in Oakridge closed in 1990, before the full effects of the spotted owl crisis could be felt; the local forest products industry decline was almost entirely the result of declining private harvest. The town, as profiled in the article, has never fully recovered, despite its location only an hour’s drive away from the second-largest city in the state. An industrial park constructed to attract new manufacturing ventures sits idle today; plans to attract amenity migrants from out of state have not proven successful.

Oakridge, unlike Sweet Home, isn’t just near the once-mighty Willamette Forest; it is surrounded by it. Its forested, mountainous setting offers excellent mountain biking, hiking, and fishing; is near to several scenic lakes; and isn’t too far from skiing. Yet Oakridge doesn’t have that combination of amenities and accessibility that has allowed other forested towns to recover or flourish in the absence of timber harvest and resource use. Similar to Sweet Home, Oakridge was never selected as a feasible depot location, regardless of cost parameters or federal harvest levels.

Cave Junction, Oregon

Cave Junction represents the new rural fate in the ever-changing resource dependent environment: places where not just the decline of timber harvest, but the decline in payments to counties associated with those harvests, have wreaked havoc on town budgets and functioning. Situated in the southern part of Josephine County, very near the border of the Rogue River-Siskiyou National Forest and the last stop along the way to Oregon Caves National Monument, Cave Junction has not experienced the same loss of mills that other places have. The Kalmiopsis Wilderness comprises much of the nearby National Forest land and was initially established in 1964, long before the declines in timber harvest attributable to federal restrictions due to endangered species.

All the communities within Josephine County, and other adjacent counties, have struggled instead with the loss of timber receipt payments to counties that accompanied federal harvest from both BLM and USFS lands. The harvest of timber on BLM and USFS-administered Oregon and California Lands – a special designation of lands that were revested railroad grant alternate sections and occurs extensively within Josephine County – remitted a particularly large percentage of the timber sale to counties for use for roads and schools. This enabled county budgets to provide other services and residents to enjoy very low property taxes, which many felt was just compensation for the high level of untaxable, undevelopable public lands within the county.

The loss of these payments has hit the so-called “O & C Counties” particularly hard. Josephine County, as detailed in a very recent radio segment and blog post by National Public Radio titled “Oregon’s Case-Strapped Counties Reject Public Safety Levies”, now has police officers on duty only during business hours (Chappell 2013). The resultant load on a state police force spread thin across the area has proven to be too much, as increases in crime, homicide, and the lack of response to domestic violence threats overwhelm the communities (K. Johnson 2013; Kavanaugh 2014). Yet local residents rejected a levy specifically earmarked to improve public safety in 2013.

Unlike Sweet Home and Oakridge, however, Cave Junction was selected for depot establishment under three scenarios, all with the low cost assumptions ($1 establishment cost per bone dry ton and $2 processing cost per bone dry ton): without the inclusion of federal biomass and with current and increased levels of federal harvest. The first two scenarios established a low capacity (25,000 bdt/annually) depot, while the increased federal harvest scenario established a medium capacity depot (50,000 bdt/annually). Despite the unreasonably low assumptions of these cost estimates, these results do provide some evidence that targeted biomass market development could be somewhat feasible in Cave Junction, where county fiscal conditions have become constrained.

What would the actual employment effects of depots be in these cases? The working assumption was of three full-time equivalent employees (3 FTE) at the depot per

25,000 bdt of operating capacity. In addition, there would be additional jobs generated in gathering, grinding, and transporting the material from the woods to the depot. Based on current experience in truck capacity, operating times of grinders, and existing crews, a crew of five (one loader/grinder operator and four truck drivers) can process 150 bdt/day of biomass (Personal Communications, John Sessions, Francisca Belart, and Rene Zamora, Oregon State University). Assuming a maximum capacity of 25,000 bdt at the depot, the prorated share of the five-person crew FTE that can supply biomass to one depot is 3.25. A conservative estimate then is of 6.25 FTE for each 25,000 bdt of depot capacity. A 50,000 bdt capacity depot may provide up to 12.5 local jobs in the woods and at the depot site, while a high capacity depot of 75,000 bdt/year may provide 18.75 jobs.

Cave Junction possesses another important feature that improves its feasibility with respect to depots: fire risk. While the historic fire regime in mixed-severity mesic systems such as those in the Klamath-Siskiyou ecosystem are not fully understood, the 500,000 acre Biscuit fire that burned most of the Kalmiopsis wilderness in 2002 generated significant attention to wildfire risk in the Klamath-Siskiyou forest types. Markets for biomass that can facilitate removal of material to further wildfire risk reduction or other ecological goals could potentially play an essential role in enhancing feasibility of restoration and risk reduction projects.

The barriers and potential for emerging technologies and increases in supply to enact real change in rural communities is exemplified through these three places and through the results of the market model of the forest products industry. There are many reasons why policy makers may wish to facilitate the use of biomass and the development of these markets, above and beyond rural development. But recognizing the limitations at hand is critical, and failing to communicate them is detrimental to rural development goals. It is inconceivable that biomass use can save every rural community and to imply such while promoting it is disingenuous. As with all limited resources, the use and development of a market for biomass entails trade-offs: trade-offs in the landowner of timber harvested, trade-offs between different locations where development of emerging technologies is feasible, trade-offs between source locations of supply in the near term as compared to the long term. While biomass use is promising for many reasons and for many communities, a rural development tool that can aid the places most affected by changes in federal forest policy remains somewhat elusive.

7.2 Future Research and Next Steps

This dissertation is an initial attempt to model emerging technologies for biomass use and potential increases in supply resulting from policy changes within an existing forest products market. To my knowledge, it is the first effort to parameterize biomass use technologies, situate them within an existing market, and attempt to explicitly incorporate the potential effects of biomass market development on rural communities. As an initial attempt, it moves our understanding of the role that this market can play in rural development forward, but there are many opportunities for furthering this work.

The biomass technology as modeled in RMTSET with extensions is basic. Refinements and more realistic scenarios with respect to costs and capacities can be incorporated. For example, establishment costs could be adjusted based on local or inferred knowledge about existing infrastructure within each community. Was there a mill there within the last five years? Is there still an industrial pad and utilities available? Or in some locations would the establishment need to be a greenfield development?

These location-specific refinements to establishment costs could make the locations chosen by the model for depot development more reflective of reality.

Modeling the dependent depots within RMTSET with extensions assumed only truck transport (utilizing larger and doubled trailers and a product at lower moisture content) between the depots and the bio-refinery of biomass, and utilized a simple cost differential to simulate a refined or slightly processed material. Greater cost savings could be realized and the feasible establishment of dependent depots is likely to be expanded with the inclusion of possible rail transport. Incorporating reduced transportation costs between locations with known rail access to the bio-refinery would further refine the accuracy of depot feasibility. This also would require validation of transshipment cost assumptions needed to model the movement of material from truck to rail cars, with or without intermediate processing. Additionally, the nature of the refined product emerging from the depot could be developed with more accuracy within RMTSET with extensions, in particular determining a likely market price for such a product. Developing the refined material emerging from intermediate processing centers would also allow for modeling of depots not dependent on a bio-refinery for purchase of the product, but instead depots that produce a refined product for local use. Additionally, there are opportunities to adapt RMTSET with extensions to model more sophisticated intermediate processing centers, perhaps based on facilities like the Integrated Biomass Campus in Wallowa County, Oregon. There, a suite of products are made from a variety of material coming from a very basic in-woods sort, where all non-sawlogs are delivered to the Biomass campus. Producing multiple outputs in order to maximize the highest value out of the input material may enable more feasible depot development in more locations, or simply the development of higher-value end products from biomass, rather than minor refinement or none at all.

One goal of many in promoting biomass market development is to facilitate restoration and wildfire risk reduction treatments on all lands, by providing a mechanism to generate some return from the removal of un-merchantable material. Lowering the per-acre treatment cost, especially on public lands, would enable limited budgets to treat more acres and would greatly improve the efficacy of treatments on a landscape level. Modeling studies have shown that significant portions of the landscape need to be treated before widespread wildfire severity and spread reductions are felt through fuel treatments.

In this analysis, however, material resulting from wildfire risk reduction treatments was not considered. In general, such restoration efforts are focused on the eastside of the state, where there are higher fire return intervals and the stand- and landscape-level consequences of decades of fire exclusion and suppression have resulted in great changes in forest structure and function. A natural and useful extension of this work is to apply it to the east side and to incorporate fuel treatment material into the southwest portion of the state to ascertain the potential rural development effects of large-scale treatments. Because RMTSET with extensions can model the biomass stemming from federal lands in a supply stream separate from biomass coming from private lands, several useful policy scenarios can be considered, including treatments occurring only on federal lands and harvest as usual on private lands, or the use of the material with and without facilities requiring the sale of RINs. Modeling such fuel or general restoration efforts would require the development of reasonable prescriptions in conjunction with silviculturists and ecologists and could provide a realistic assessment of the potential for treatments to assist rural communities. In addition, the spatial nature and the use of detailed plot inventories in the market-driven RMTSET model can also be used to assess the wildfire risk reduction potential of treatments occurring within the context of a developed biomass market. Stand structure results from RMTSET, used in conjunction with fire spread and severity models, can be used to compare the effectiveness of fuel treatments done with and without a viable market that can make treatment of more acres across the landscape economically feasible.

The use of RMTSET and RMTSET with extensions has proven valuable in assessing the potential for emerging technologies and increased supply to affect change in rural communities, and to compare these effects spatially across a large region. It is my sincere wish that these results can be used in a realistic fashion to move forward the idea of capturing the most value from a limited resource – wood – in a way that has the maximum benefit to society as a whole, including economic, social, and ecological goals. There is no ‘silver bullet’ or easy fix to the problems facing many rural, forest-dependent communities, but the development of strategies that can provide forward movement on these goals is important. Assessing the realistic potential for these, and situating them within a market context, provides the highest likelihood of success.

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Appendix

The detailed estimation of demand parameters for western Oregon are reported in Guerrero 2010. These have not yet been published. The Washington estimation procedure and results are described in this appendix to illustrate the methodology and models used in the Oregon estimates that are key inputs to RMTSET for western Oregon.

The Wiley, Smith, and Bramble approach for ensuring the convexity of the Hessian matrix of estimated coefficients replaces the matrix *H* with the estimated triangular matrix AA’ for $\hat{H}$ as follows:

$$H = \begin{bmatrix} \beta_{00} & \beta_{01} & \beta_{02} \\ \beta_{01} & \beta_{11} & \beta_{12} \\ \beta_{02} & \beta_{12} & \beta_{22} \end{bmatrix}$$

$$\widehat{H} = AA' = \begin{bmatrix} a_{00}^2 & a_{00} * a_{01} & a_{00} * a_{02} \\ a_{00} * a_{01} & a_{01}^2 * a_{11}^2 & a_{01} * a_{02} + a_{11} * a_{12} \\ a_{00} * a_{02} & a_{01} * a_{02} + a_{11} * a_{12} & a_{02}^2 * a_{12}^2 * a_{22}^2 \end{bmatrix}$$

The selection process of the final models used for Western Washington lumber and plywood industries compared the results of several alternative specifications. The estimation results of these alternative specifications and the model selected are detailed in Table 28 and Table 29 below for lumber and plywood, respectively.

For lumber, models estimated included with the data in first differences only, with differenced data plus a correction for autocorrelation (AUTO in SHAZAM, which applies a single autocorrelation parameter *rho* (ρ) to the entire system), with differenced data and a correction for autocorrelation that assigns a separate *rho* to each equation (DRHO in SHAZAM), and with the data in levels with an autocorrelation correction (DRHO). For plywood, models included the data in first differences, first differenced data plus equation-specific autocorrelation corrections, and the former with curvature restrictions included as well. All models imposed cross-symmetry of coefficients between equations as part of the model specification.

Table 28. Models Estimated of the Western Washington Lumber Industry.

	Model 1: First Differences			Model 2: 1st Differences, Autocorrelation (eqn specific terms)		
Variable	Parameter	Estimate	Asy. T-Ratio	Parameter	Estimate	Asy. T-Ratio
Y_p	β_0	0.1017	1.1423	β_0	0.0972	0.86213
S_p	β_1	-0.0537	-0.97401	β_1	-0.0456	-0.61865
L_p	β_2	-0.2608	-1.2096	β_2	-0.2427	-0.71039
Y_p^2	β_{00}	0.0060	7.400	β_{00}	0.0060	7.052
S_p^2	β_{11}	0.0021	3.2677	β_{11}	0.0019	2.9602
L_p^2	β_{22}	0.1901	2.9814	β_{22}	0.1741	3.2085
Y_pS_p	β_{01}	-0.0032	-5.627	β_{01}	-0.0031	-5.433
Y_pL_p	β_{02}	-0.0087	-2.2778	β_{02}	-0.0085	-2.4125
S_pL_p	β_{12}	0.0058	1.4612	β_{12}	0.0060	1.6613
Y_pK	β_{0k}	0.4586	2.2578	β_{0k}	0.3201	1.5041
S_pK	β_{1k}	-0.2624	-2.1026	β_{1k}	-0.1732	-1.3161
L_pK	β_{2k}	-0.1742	-0.378	β_{2k}	0.3305	0.6843
Y_pT	β_{0t}	-0.0039	-1.055	β_{0t}	-0.0031	-0.64883
S_pT	β_{1t}	0.0028	1.1876	β_{1t}	0.0020	0.65874
L_pT	β_{2t}	0.0129	1.4422	β_{2t}	0.0106	0.77811
K	β_k	108.88	1.1152	β_k	123.18	1.2701
T	β_t	-4.5649	-1.7241	β_t	-4.2463	-1.4347
KT	β_{kt}	-5.3732	-1.1953	β_{kt}	-5.2309	-1.151
T^2	β_{tt}	0.1376	2.178	β_{tt}	0.1300	1.8949
K^2	β_{kk}	353.00	2.8283	β_{kk}	350.65	2.6634
Intercept	α_0	1.9401	0.07315	α_0	-2.0232	-0.066164
	D-W			D-W	ρ	Asy. T-Ratio
Eqn 34	1.9665			1.7090	-0.1004	-0.71824
Eqn 35	1.6832			1.8838	0.1070	1.0265
Eqn 36	1.8452			2.0628	0.1484	1.3405
Eqn 37	1.6828			2.2046	0.3102	2.4282
Eigenvalues (H)	0.1906	0.007243	0.0002566	0.174696	0.0070526	0.000228

Table 28 (con't). Models Estimated of the Western Washington Lumber Industry.

	Model 3: 1st Differences, Autocorrelation (single term)			Model 4: Levels, Autocorrelation (eqn specific terms)		
Variable	Parameter	Estimate	Asy. T-Ratio	Parameter	Estimate	Asy. T-Ratio
Y_p	β_0	0.0978	0.87925	β_0	1.3094	2.1458
S_p	β_1	-0.0467	-0.67242	β_1	-1.2989	-3.312
L_p	β_2	-0.2444	-0.92402	β_2	-15.7680	-8.0578
Y_p^2	β_{00}	0.0059	7.061	β_{00}	0.0048	2.767
S_p^2	β_{11}	0.0019	3.1064	β_{11}	0.0013	1.5992
L_p^2	β_{22}	0.1836	3.0875	β_{22}	0.1485	2.5239
Y_pS_p	β_{01}	-0.0031	-5.355	β_{01}	-0.0024	-2.160
Y_pL_p	β_{02}	-0.0081	-2.1523	β_{02}	-0.0053	-1.145
S_pL_p	β_{12}	0.0052	1.3769	β_{12}	0.0007	0.19365
Y_pK	β_{0k}	0.4756	2.2968	β_{0k}	0.4722	2.4173
S_pK	β_{1k}	-0.2686	-2.1015	β_{1k}	-0.2608	-2.1723
L_pK	β_{2k}	-0.1060	-0.22005	β_{2k}	-0.1729	-0.40347
Y_pT	β_{0t}	-0.0038	-0.8122	β_{0t}	-0.0118	-0.55553
S_pT	β_{1t}	0.0025	0.86505	β_{1t}	0.0288	2.1355
L_pT	β_{2t}	0.0122	1.1453	β_{2t}	0.0938	1.4532
K	β_k	104.62	1.0398	β_k	12.11	1.2073
T	β_t	-3.3354	-0.90906	β_t	-5.2986	-1.7142
KT	β_{kt}	-5.0488	-1.0965	β_{kt}	2.0180	0.77871
T^2	β_{tt}	0.1115	1.3621	β_{tt}	-0.0529	-0.22606
K^2	β_{kk}	372.44	2.7243	β_{kk}	-6.59	-0.9706
Intercept	α_0	-11.5810	-0.30009	α_0	12.9450	1.6059
	ρ	0.0937	1.0182			
	D-W			D-W	ρ	Asy. T-Ratio
Eqn 34	2.1375			1.4981	0.2182	1.6932
Eqn 35	1.8422			1.2878	0.7816	14.759
Eqn 36	1.9715			1.4925	0.7998	15.12
Eqn 37	1.8596			1.5116	0.7923	16.008
Eigenvalues (H)	0.184068	0.00701148	0.0002362	0.1486608	0.0058097	0.0000553

Table 29. Models Estimated of Western Washington Plywood Industry.

	Model 1: First Differences			Model 2: 1st Differences, Autocorrelation (eqn specific terms)		
Variable	Parameter	Estimate	Asy. T-Ratio	Parameter	Estimate	Asy. T-Ratio
Y_p	β_0	-0.0145	-0.37194	β_0	-0.0049	-0.089882
S_p	β_1	0.0169	1.2537	β_1	0.0157	0.89334
L_p	β_2	0.3401	2.7535	β_2	0.4568	5.0681
Y_p^2	β_{00}	0.0029	6.297	β_{00}	0.0029	7.368
S_p^2	β_{11}	0.0002	2.8458	β_{11}	0.0002	2.4695
L_p^2	β_{22}	0.0310	0.76114	β_{22}	0.0120	0.32841
Y_pS_p	β_{01}	-0.0009	-5.302	β_{01}	-0.0009	-5.201
Y_pL_p	β_{02}	-0.0025	-1.5929	β_{02}	0.0000	0.028524
S_pL_p	β_{12}	-0.0010	-0.90101	β_{12}	-0.0021	-2.0049
Y_pK	β_{0k}	0.3051	1.3024	β_{0k}	0.2256	0.90419
S_pK	β_{1k}	-0.0823	-1.0172	β_{1k}	-0.0522	-0.62248
L_pK	β_{2k}	-0.2488	-0.32439	β_{2k}	0.0265	0.041153
Y_pT	β_{0t}	-0.0001	-0.040839	β_{0t}	-0.0008	-0.44417
S_pT	β_{1t}	-0.0004	-0.65579	β_{1t}	-0.0002	-0.2876
L_pT	β_{2t}	-0.0088	-1.8102	β_{2t}	-0.0123	-3.3966
K	β_k	-64.42	-0.71984	β_k	1.03	1.028
T	β_t	-1.0991	-1.0792	β_t	-2.8705	-1.1787
KT	β_{kt}	4.1006	1.2544	β_{kt}	2.4863	2.1843
T^2	β_{tt}	0.0255	1.1074	β_{tt}	0.0620	0.75511
K^2	β_{kk}	-188.48	-0.58471	β_{kk}	0.77	0.76444
Intercept	α_0	14.5980	1.4972	α_0	1.1632	1.1632
	D-W			D-W	ρ	Asy. T-Ratio
Eqn 34	2.0253			2.5511	0.9660	24.329
Eqn 35	1.7282			1.4565	-0.1927	-2.2095
Eqn 36	1.7045			1.4609	-0.1918	-2.1918
Eqn 37	2.3459			2.0216	-0.1986	-2.2668
Eigenvalues (H)	0.03125322	0.003014022	-0.0001284	0.01236775	0.0030903	-0.000366081

Table 29 (con't). Models Estimated of Western Washington Plywood Industry.

	Model 3: 1st Differences, Autocorrelation, Curvature Restrictions			
Variable	Parameter		Estimate	Asy. T-Ratio
Y_p	β_0		-0.0410	-0.58611
S_p	β_1		0.0274	1.1211
L_p	β_2		0.4424	3.7599
	A_{00}		-0.0519	-13.229
	A_{01}		0.0172	9.6608
	A_{11}		0.0025	0.92521
	A_{02}		0.0477	1.922
	A_{12}		-0.0153	-1.7708
	A_{22}		-0.0176	-0.096138
Y_pK	β_{0k}		0.1651	0.767
S_pK	β_{1k}		-0.0188	-0.25851
L_pK	β_{2k}		0.3464	0.51458
Y_pT	β_{0t}		0.0009	0.32238
S_pT	β_{1t}		-0.0007	-0.65376
L_pT	β_{2t}		-0.0122	-3.0121
K	β_k		-112.17	-4.0123
T	β_t		-0.2359	-0.34461
KT	β_{kt}		2.4365	3.7859
T^2	β_{tt}		0.0109	0.70316
K^2	β_{kk}		-180.98	-9.0504
Intercept	α_0		2.5414	0.36858
Y_p^2	β_{00}	A_{00}^2	0.00	6.6144
S_p^2	β_{11}	$A_{01}^2 + A_{11}^2$	0.0003	5.1272
L_p^2	β_{22}	$A_{00}^2 + A_{12}^2 + A_{22}^2$	0.0259	0.92631
Y_pS_p	β_{01}	$A_{00} * A_{01}$	-0.0009	-5.9432
Y_pL_p	β_{02}	$A_{00} * A_{02}$	0.00	-1.9948
S_pL_p	β_{12}	$A_{00} * A_{02} + A_{00} * A_{02}$	0.0004	0.686327
	D-W		ρ	Asy. T-Ratio
Eqn 34	1.6950		-0.2967	-1.9318
Eqn 35	1.5017		-0.1798	-1.8252
Eqn 36	1.5162		-0.1564	-1.6813
Eqn 37	2.0649		-0.2167	-1.9107
Eigenvalues (H)	0.02614255		0.002720479	0.00000007

Selection of the final models for both lumber and plywood industries was done by considering the results of the tests applied (stationarity, cointegration, and the Durbin-Watson test for autocorrelation), the performance of the estimated models, the signs of the eigenvalues for the coefficient matrix, and the resulting elasticities calculated. Elasticites by estimated model for western Washington lumber and plywood are shown in Table 30 and Table 31, respectively.

None of the western Washington lumber models had negative eingenvalues. There was evidence of non-stationarity, so the models using data in first differences were preferred. Model three returned a non-negative own-price elasticity for logs, which contradicts economic theory. Models one and two returned very similar estimates of elasticity (-0.32233 and -0.30377, respectively). The simplest model with good results, Model one, was selected. This is the same specification selected for estimating the western Oregon lumber industry profit function and elasticities.

Western Washington plywood industry data also showed signs of non-stationarity, so all models were estimated using differenced data. Results from Models one and two both had a slightly negative third eigenvalue. However, the addition of curvature corrections resulted in a non-negative own-price log elasticity, contradicting economic theory. Models one and two produced similar elasticity estimates (-0.25467 and -0.25052, respectively), indicating some stability around that number. The minimal amount of negativity of the eigenvalue was determined to be acceptable given the resulting elasticity estimate and the simple model of differenced data only was again selected. For western Oregon, in contrast, the plywood industry model did incorporate curvature constraints.

Table 30. Elasticity estimates for western Washington lumber models.

	Model 1: First Differences			Model 2: 1st Differences, Autocorrelation (eqn specific terms)		
		Estimate	Apx. P Value		Estimate	Apx. P Value
e_{yy}	β_{00} (Y_p/Y_q)	0.500039	0.000	β_{00} (Y_p/Y_q)	0.495326	0.000
e_{sy}	β_{01} (Y_p/S_q)	0.462821	0.000	β_{01} (Y_p/S_q)	0.449076	0.000
e_{ly}	β_{02} (Y_p/L_q)	0.208115	0.02274	β_{02} (Y_p/L_q)	0.202053	0.01585
e_{ys}	β_{01} (S_p/Y_q)	-0.2913	0.000	β_{01} (S_p/Y_q)	-0.28265	0.000
e_{ss}	β_{11} (S_p/S_q)	-0.32233	0.00108	β_{11} (S_p/S_q)	-0.30377	0.00307
e_{ls}	β_{12} (S_p/L_q)	-0.14989	0.14397	β_{12} (S_p/L_q)	-0.15518	0.09666
e_{yl}	β_{02} (L_p/Y_q)	-0.08661	0.02274	β_{02} (L_p/Y_q)	-0.84091	0.01585
e_{sl}	β_{12} (L_p/S_q)	-0.09911	0.14397	β_{12} (L_p/S_q)	-0.10261	0.09666
e_{ll}	β_{22} (L_p/L_q)	-0.54514	0.00287	β_{22} (L_p/L_q)	-0.49915	0.00133

	Model 3: 1st Differences, Autocorrelation (single term)			Model 4: Levels, Autocorrelation (eqn specific terms)		
		Estimate	Apx. P Value		Estimate	Apx. P Value
e_{yy}	β_{00} (Y_p/Y_q)	0.00588	0.000	β_{00} (Y_p/Y_q)	0.395723	0.006
e_{sy}	β_{01} (Y_p/S_q)	-0.00305	0.000	β_{01} (Y_p/S_q)	0.342241	0.031
e_{ly}	β_{02} (Y_p/L_q)	-0.00808	0.03138	β_{02} (Y_p/L_q)	0.125739	0.2522
e_{ys}	β_{01} (S_p/Y_q)	-0.00305	0.000	β_{01} (S_p/Y_q)	-0.21541	0.031
e_{ss}	β_{11} (S_p/S_q)	0.00189	0.00189	β_{11} (S_p/S_q)	-0.20123	0.10977
e_{ls}	β_{12} (S_p/L_q)	0.005184	0.16855	β_{12} (S_p/L_q)	-0.01874	0.84645
e_{yl}	β_{02} (L_p/Y_q)	-0.00808	0.03138	β_{02} (L_p/Y_q)	-0.05233	0.2522
e_{sl}	β_{12} (L_p/S_q)	0.005184	0.16855	β_{12} (L_p/S_q)	-0.01239	0.84645
e_{ll}	β_{22} (L_p/L_q)	0.18354	0.00202	β_{22} (L_p/L_q)	-0.42576	0.01161

Table 31. Elasticity estimates for western Washington plywood models.

	Model 1: First Differences			Model 2: 1st Differences, Autocorrelation (eqn specific terms)		
		Estimate	Apx. P Value		Estimate	Apx. P Value
e_{yy}	$\beta_{00}\ (Y_p/Y_q)$	0.63279523	0.000	$\beta_{00}\ (Y_p/Y_q)$	0.6282476	0.000
e_{sy}	$\beta_{01}\ (Y_p/S_q)$	0.5847845	0.000	$\beta_{01}\ (Y_p/S_q)$	0.5685584	0.000
e_{ly}	$\beta_{02}\ (Y_p/L_q)$	0.1514866	0.11118	$\beta_{02}\ (Y_p/L_q)$	-0.002864	0.97724
e_{ys}	$\beta_{01}\ (S_p/Y_q)$	-0.3176665	0.000	$\beta_{01}\ (S_p/Y_q)$	-0.308852	0.000
e_{ss}	$\beta_{11}\ (S_p/S_q)$	-0.2546677	0.0043	$\beta_{11}\ (S_p/S_q)$	-0.250527	0.01353
e_{ls}	$\beta_{12}\ (S_p/L_q)$	0.0965357	0.36758	$\beta_{12}\ (S_p/L_q)$	0.2097719	0.04498
e_{yl}	$\beta_{02}\ (L_p/Y_q)$	-0.0684993	0.111	$\beta_{02}\ (L_p/Y_q)$	0.0012952	0.97724
e_{sl}	$\beta_{12}\ (L_p/S_q)$	0.0803572	0.36758	$\beta_{12}\ (L_p/S_q)$	0.174616	0.04498
e_{ll}	$\beta_{22}\ (L_p/L_q)$	-0.2346286	0.44657	$\beta_{22}\ (L_p/L_q)$	-0.090683	0.7426

	Model 3: 1st Differences, Autocorrelation, Curvature Restrictions		
		Estimate	Apx. P Value
e_{yy}	$\beta_{00}\ (Y_p/Y_q)$	0.0058797	0.000
e_{sy}	$\beta_{01}\ (Y_p/S_q)$	-0.003051	0.000
e_{ly}	$\beta_{02}\ (Y_p/L_q)$	-0.0080774	0.04606
e_{ys}	$\beta_{01}\ (S_p/Y_q)$	-0.003051	0.000
e_{ss}	$\beta_{11}\ (S_p/S_q)$	0.00188959	0
e_{ls}	$\beta_{12}\ (S_p/L_q)$	0.0051838	0.49251
e_{yl}	$\beta_{02}\ (L_p/Y_q)$	-0.0080774	0.04606
e_{sl}	$\beta_{12}\ (L_p/S_q)$	0.0051838	0.49251
e_{ll}	$\beta_{22}\ (L_p/L_q)$	0.18354	0.21134