TITLE: Biomass Supply Curves for Western Juniper in Central Oregon, USA, Under Alternative Business Model and Policy Assumptions

Abstract:

This study estimates a supply of juniper from private lands to determine how much of the available juniper (*Juniperus occidentalis* Hook) can be economically supplied at alternative prices if a market were to develop for using juniper as a biomass source. While juniper is native to central OR, current land management practices have led to a significant increase in its density on much of the landscape. There could be potential benefits related to juniper removal for private landowners, as well as social benefits associated with water and habitat enhancement. At current densities, juniper on these private lands has negative impacts that diminish biodiversity, reduce forage grass and tie up water resources. The difference in the value of cattle productivity resulting from the presence of juniper as well as any forgone net returns from the sale of juniper to the biofuel industry reflects the opportunity cost to the rancher. This opportunity cost does not capture the complete opportunity cost associated with juniper removal since it does not incorporate the enhanced benefits of biodiversity and increased water availability, and thus reflects a lower bound. The supply curves for juniper as a source for biofuel shift in response to profitable harvesting coordination between landowners, the Oregon Biofuel Producer tax credit and increased positive externalities due to juniper removal. Because of restricted road networks the available source of juniper was limited by access --only 27% of the juniper area is on private rangelands, which is the focus of this report. This study identified supply costs under alternative business models and policy assumptions for an aggregate supply of 2.75 million tonnes and illustrated an analytic technique that could be replicated in other areas.

Keywords: western juniper, biomass, supply, cost, biofuel, simulated annealing

1. Introduction

Native to the United States, western juniper (*Juniperus occidentalis* Hook) has expanded its range in the absence of historically limiting factors. Western juniper forests span 14 eastern Oregon counties and comprising 1.5 million hectares are the largest source of forest biomass next to the fuel treatment of over-stocked forestlands (Bowyer et al. 2006). A majority of the western juniper woodlands came into existence in the last 130 years and in Eastern Oregon, those stands with 10 percent canopy cover were estimated at 456,000 acres in 1936 and 2.2 million acres in 1988 (Miller et al. 2005). Western juniper now covers 9 million acres across Oregon, California, Nevada, and Idaho and is still expanding. This acreage is considered to be predominantly in a transitional state from shrub-steppe to juniper woodlands. Densities of trees in developed woodlands vary greatly from 32 acre^{-1} trees in dry locations and as much as 500 trees acre^{-1} in cool moist sites (Miller et al. 2005). There is also evidence that suggests that the end of the Little Ice Age in Oregon, ending in 1850, has contributed to juniper expansion as a result of warmer and wetter conditions (Miller et al. 2005). When livestock grazing began in the 1860's fuel loads were reduced and thus reduced the fire severity, but also served to reduce competition to western juniper from grass and shrubs (Burkhardt and Tisdale 1976).

The expansion of western juniper reduces soil moisture, duration of seasonal stream flows, and ecosystem service production (Deboodt 2008). Juniper removal can improve range productivity, reduce fire hazard, and enhance wildlife habitat (Miller et al. 2005). Previous attempts to utilize juniper for commercial scale endeavors have been thwarted by its difficulty to harvest and a lack of available markets (McNeel and Swan 1994). The development of new biofuel technologies could create a reliable and sustained demand for juniper as a feedstock material.

The objective of this study is to estimate the supply curves for juniper, from private lands in Central Oregon, USA. These supply curves provide information on how much juniper would be available at alternative prices if a biomass market were to develop. The difference in the value of cattle productivity resulting from the presence of juniper, as well as any forgone net returns from the sale of juniper to a biofuel industry reflect the opportunity cost to the rancher of not participating in a juniper biomass market. As the opportunity cost rises, due to rising net returns and/or declining cattle productivity, more acreage (or tonnage) of juniper will be supplied. In addition, this study explores the potential impact of rangeland improvements and other market impacts on these supply relationships.

An economic model is developed to derive the juniper supply curves with and without subsidies under several business models. The resulting discrete optimization problem is solved using simulated annealing. Net returns are dependent upon revenues from the sale of juniper to the biomass market and the costs. Harvesting costs for a likely combination of harvesting, chipping, and truck transport equipment are developed and applied to private forest lands within 64 kilometers of Prineville, Oregon (Fig. 1). The spatial location and inventory volume (dry tonnes) is estimated using Geographic Information Systems (GIS) and remotely sensed data. (Fig. 2)

Prineville is the largest city in Crook County, which holds the highest densities of western juniper in Oregon, 2.9 million bone dry tons (Azuma et al. 2005). Prineville was chosen as the center of the study because it serves as a centralized location for biomass collection, with access to railway transportation for the final biofuel product. This location was identified by a company seeking to construct a biofuel facility (Oregon BEST 2012), because it has abundant biomass feedstock and access to transportation.

The structure of the paper is as follows: the economic model with varying market characteristics is presented to provide a context for the four supply curves, which are captured in the four scenarios. The process used to generate the necessary GIS data is outlined in an ancillary appendix. The formulation of the cost of harvest and transport, followed by a model which captures the ecosystem service production and benefits that would be achieved through juniper removal is provided in the Appendix. The solution method for generating the results for the supply curves for juniper is discussed. Lastly, the results and discussion section point to the key findings and implications of this study, relating the results to ongoing policy discussions concerning biomass, scales of production and the current climate for supporting alternative energy markets.

Figure 1: Study Area

Figure 2: Map of Available Roadside Juniper.

2. Economic Model and Solution Methods

2.1. Economic Model

The supply curves for juniper modeled in this research represent the most likely price/quantity combinations that will be forthcoming from private lands. While the development of a biomass market will lead to innovation, and further development of infrastructure that cannot be completely anticipated ex ante, this analysis provides a structural approach to understanding key factors that will influence the behavior of private landowners participating in such a market, and the resulting supply of juniper biomass. The types and scale of firms/lands, and the location of sources of juniper affect the overall juniper supply. Technological developments in harvesting equipment and biomass to energy conversion also affect the supply of juniper. Western juniper, unlike many forest species that are currently harvested commercially, is scattered across the landscape in widely varying concentrations. Thus the mobilization of equipment to harvest juniper can be a significant component of overall cost. Planning and coordination may allow firms to realize cost savings by visiting multiple adjacent sites on the same trip. If there are many firms in the business of harvesting juniper, coordination between firms might be challenging. Alternatively, if there is a single firm (or only a few firms) then firms may take advantage of the cost savings that would come with coordinating their movement among production landings.

A second consideration is what type of firm will do the harvesting. This is commonly referred to as the degree of vertical integration and will depend upon the cost advantages associated with this newly emerging industry. One possibility is that the processing plant also does the harvesting: a single (large) firm that may be able to reduce move-in costs associated with coordinating movement between landings. However the firm may be unable to benefit from the improved productivity of the land associated with juniper removal, if it does not own the land and is not engaged in cattle production. The inability to benefit from the increased rangeland productivity, would lead to lower levels of harvest compared to the socially optimal level. Alternatively, if ranchers are the firms who harvest the juniper, the positive benefits associated with enhanced cattle productivity and net returns will be reflected in the opportunity costs and thus the juniper supply. However, it is likely that the cost savings of move-in coordination efforts (i.e., reductions in harvesting costs) may not be initially realized in an emerging market, due to high transaction costs between multiple land owners and underdeveloped infrastructure.

In order to better understand how different market structures might affect supply, several different models for profit maximization are developed and explored. In all of the scenarios we assume that the harvesting firm or firms, which could be the biofuel producer, ranchers or independent contractor(s), will only harvest a parcel if the marginal revenue from harvesting that parcel exceeds the marginal cost of harvesting. We also assume the forest area is divided into rectangular parcels equal to 0.4 ha (1.0 acre) due to the spatial resolution of the vegetation data.

Scenario 1: Non-Coordinated Profit Maximization

The firm will maximize profits by visiting profitable landings, and cutting the parcels that can be removed cost effectively from that landing. This means that some parcels that would be accessible at a given landing would be left intact, if they are not dense enough, or too far from the road to make harvesting economically viable.

In order to harvest a particular parcel, a landing for the harvesting equipment must be established within 800 meters (½ mile) of the parcel being considered. The decision the producer must make is which landings to visit. Once at a landing, the parcels to be harvested are determined by the price. So the firm's problem is to find the set of landings that maximizes profit.

$$\pi(y) = max_{y \in Y}\left\{\sum_{j=1}^{k}\left[\sum_{i=1}^{n}[P * V_{ij} - c_h\left(x_{ij}(P)\right)] - c_m\left(y_j\right)\right]\right\} \quad (Eq. 1)$$

$\pi(y)$ = profit at landings visited

P= price per ton

V_{ij}= total volume harvested from parcel i at landing j

Y = Set of all available landings

y = Set of landings visited, this set is indexed by j=1,2,3,…,k

x_{ij} = A parcel harvested at landing y_j. The parcels belonging to this set are a function of the price and are indexed by i=1,2,3…,n

c_h = cost of biomass harvest plus biomass transportation to processing plant for parcel x_{ij}

c_m = harvest equipment move in cost.

The cost of harvest is separated into two separate components. The variable cost associated with the harvest, processing and transport of the biomass at the parcel level, and the move-in cost associated with delivering machines to a particular landing. In order to decide whether or not to harvest a given parcel we apply the principle that the revenue from harvesting that parcel must be greater than or equal to the cost of harvesting. Move-in costs associated with visiting a landing are not a function of volume. Since we assume in this scenario that the harvesting equipment must be brought from the central processing plant, any landing where the total revenue minus the total harvest costs exceeds the move-in costs should be visited.

Scenario 2: Coordinated Profit Maximizing Harvest Model

In this scenario it is assumed that a harvesting firm is able to coordinate the movement of machines through the landscape in order to reduce the move in costs. The cost of visiting a landing is directly related to which other landings are visited. It is impossible to divide up the cost of moving into a landing and assign a portion of that fixed cost to each parcel. In other words, the cost of visiting a particular landing could be decreased if there are other landings that can be easily accessed close by. The firm's problem is basically the same as the previous scenario except for now c_m is a function of all of the landings in the solution set, rather than the sum of the costs associated with each individual landing.

$$\pi(y) = \ max_{y \in Y}\left\{\left[\sum_{j=1}^{k}\sum_{i=1}^{n} P * V_{ij} - c_h\left(x_{ij}(P)\right)\right] - c_m(y)\right\} \quad (Eq.2)$$

Scenario 3: Rangeland Productivity Improvement

For scenario 3, the harvesting decision is affected by several other incentives; we consider two additional factors. Removing juniper increases the quality of the range, improving its productivity for cattle ranching. Additionally, the state of Oregon offers a tax credit that subsidizes the production of biomass at a rate of $10 per oven-dry English short ton.

In this scenario ranch owners represent the firms making the harvesting decision since they are the most likely to incorporate the positive externalities of juniper removal into the harvesting decision. We assume that transaction costs associated with coordinating movement of harvesting equipment to many different ranches would be prohibitively high, so we use the model that specifies that the equipment is returned to a central location. When these additional incentives for juniper harvest are included the final model is the following:

$$\pi(y) = \ max_{y \in Y}\left\{\sum_{j=1}^{k}\left[\sum_{i=1}^{n}[P * V_{ij} - c_h\left(x_{ij}(P)\ \right) + g_i + t * V_i] - c_m\left(y_j\right)\right]\right\} \quad (Eq.3)$$

Where all variables are defined as in Eq. 1 and:

g_i = the value of the improvement in the quality of the range

t = the rate of the biomass tax credit

Scenario 4: Coordinated Harvest + Rangeland Improvement

This scenario includes both positive externalities and cost savings created by coordinating move-in efforts. This scenario is useful to explore how an innovative firm might take advantage of all of the available cost savings. The model is the same as described in Scenario 3, Eq. 3 except for move-in costs are a function of all the landings visited.

$$\pi(y) = \ max_{y \in Y} \left\{ \left[\sum_{j=1}^{k} \sum_{i=1}^{n} P * V_{ij} - c_h\big(x_{ij}(P),\big) + g_i + t * V_i \right] - c_m(y) \right\} \quad (Eq. 4)$$

2.2. Solution Method

The solution method depends upon the assumed business model. If a complete mobilization from the central plant location was required for each landing, the solution can be determined for each price level by harvesting all of the 0.4 ha parcels at a given landing where the revenue from harvesting that parcel is greater than or equal to the cost of harvesting that parcel. Which landings are visited is determined by comparing the move-in costs for that landing to the total revenue minus the total harvest cost for that landing. If travel between landings is permitted, the cost of visiting each individual landing cannot be separated from the cost of visiting all of the landings in the solution set. This becomes a variation of the traveling salesman problem, which can be formulated as an integer program. However, more than 1000 potential landings have been identified on our landscape. This means that there are more than 2^{1000} different possible combinations of landings that could be harvested, making the problem very difficult to solve as an integer program. Instead a simulated annealing heuristic algorithm (Kirkpatrick et al. 1983), is used to try to find the best possible combination of landings for a given biomass price. A description of the simulated annealing algorithm and its implementation for this problem is outlined below:

Step 1: A price level is set and the set of parcels that will be harvested at each landing is established.

Step 2: A random initial solution for which landings will be visited is generated.

Step 3: A small change is made to the initial solution.

Step 4: The objective function for the new solution is calculated. The objective is the profit function and includes the costs and revenue associated with harvesting the parcels associated with every landing visited. It also includes the move in costs associated with visiting every landing in the solution. (Eq. 3)

Step 5: The value of the new objective function is compared to the value of the current objective function. If the change to the solution set improves the profitability then the change is kept and the new solution becomes the current solution. If the new solution is not better than the old solution, there is still some probability that the solution will be kept. This helps to avoid local maximums. The probability of keeping a new solution that is worse than the current solution is based on the formula:

$$prob = \frac{1}{e^{\delta/_{temp}}} \quad (Eq. 5)$$

$\delta = current\ objective\ value - new\ objective\ value$

$temp = temperature\ parameter$

$e = mathematical\ constant, 2.718.$

At high values of temp, the probability of keeping a worse solution is relatively high. As the algorithm progresses temp decreases, causing the probability of keeping a worse solution to decrease, until there is only a very small chance that a worse solution will be accepted.

Step 6: Steps 3-5 are repeated until the specified number of repetitions and the ending t is reached. Any time a solution is found that is better than any solution previously seen it is saved so that there is always a record of the best solution found.

Step 7: The process is repeated for each price level of interest.

Several important assumptions were made when calculating these solutions. First when calculating move-in costs, it is assumed that the harvesting equipment always travels to the next closest landing that has not already been visited. This is not necessarily the shortest possible travel distance, but we feel it is a reasonable assumption to avoid a more complicated optimization routine. Second we use linear distances between landings rather than road distance to calculate move-in costs. Third we assume that harvesting equipment can be driven rather than trucked between landings if the distance is short enough. This may not be possible on all roads since the equipment travels very slowly.

3. Results

In this section we discuss the results for each of the four scenarios, and provide some economic intuition for the findings.

Scenario 1: Non-Coordinated Profit Maximization

In this scenario (Table 1) no positive externalities are accounted for and harvesting equipment must be returned to the central plant (i.e. no driving between landings). This situation might apply to multiple third party contractors, who do not benefit from coordinating move-in expenditures/effort and do not account for positive externalities associated with juniper removal. No parcels were harvested below \$55 ODT^{-1}. Returns on investment do not exceed 10% for prices below \$85 ODT^{-1}. Supply is very elastic at low prices but becomes increasingly inelastic at high prices (Fig. 3).

Table 1. Landings visited, parcels harvested, return on investment and elasticity of supply for Scenario 1, Non-Coordinated Profit Maximization

Scenario 2: Coordinated Profit Maximizing Harvest Model

In this scenario (Table 2) no positive externalities are accounted for harvesting but equipment can be driven between landings. This scenario likely applies to a single firm like the processing facility or a few large firms. A positive supply is found at \$55 ODT^{-1} and returns on investment exceed 10% at prices greater than \$65 ODT^{-1} (Table 2). In this case we have a positive supply at a lower price level. We also note that the results are less elastic (Fig. 3). There is a smaller percentage of the biomass harvested at each landing, but more total landings are visited.

Table 2. Landings visited, parcels harvested, return on investment and elasticity of supply for Scenario 2, Coordinated Profit Maximizing Harvest Model.

Scenario 3: Rangeland Productivity Improvement

In this scenario (Table 3) positive externalities are accounted for (grazing, tax credit), but a return to the plant is required. This scenario might apply to ranchers who rent equipment or contract a third party to cut juniper on their land. For Scenario 3 supply is still elastic but less elastic in the lower range of the curve (Fig. 3). Returns on investment exceed 10% when the price level is greater than \$40 ODT^{-1}. A larger percentage of the parcels available at each landing are harvested for a given price level.

Table 3. Landings visited, parcels harvested, return on investment and elasticity of supply for Scenario 3, *Rangeland Productivity Improvement.*

Scenario 4: Coordinated Harvest + Rangeland Improvement

This scenario (Table 4) is the best case scenario where the harvesting firm takes advantage of the cost savings from coordinated move-in efforts and the positive externalities associated with juniper removal. Returns on investment exceed 10% at all price levels. The supply curve becomes inelastic relatively quickly, and becomes asymptotic at approximately \$50 ODT^{-1} (Fig. 3).

Table 4. Landings visited, parcels harvested, return on investment and elasticity of supply for Scenario 4, Coordinated Profit Maximizing Harvest Model+ *Rangeland Improvement*.

3.1. Supply Curves

The information in Tables 1-4 can be used to construct a supply curve for juniper from the private lands. These are shown in Figure 3. Supply curves for all scenarios were sensitive to small changes in price over most of the price range examined, are nonlinear and become asymptotic at higher prices. We compare the scenarios across four different prices for juniper biomass quantities (Table 5), and at \$75 ODT^{-1} we examine the average percentage of a harvest unit that is harvested, the return on investment, and the elasticity of supply. At \$75 ODT^{-1}, the return on investment is almost triple in Scenario 2 compared to Scenario 1. When the price is \$75 ODT^{-1} in Scenario 1, approximately 12% of the total available biomass has been harvested and in Scenario 2, approximately 51% has been harvested. This represents an increase of approximately 111,000 ODT harvested or supplied for the same price per tonne. These results suggest that there are likely to be considerable efficiency gains for a firm that can coordinate the harvest of juniper from multiple harvest units. The highest supply at a given price is achieved if the harvest of juniper can be coordinated between multiple harvest units, biomass collectors and landowners receive biomass subsidy credits, and ranchers can take advantage of higher forage production (Scenario 4).

The supply curves do not consider business overhead or risk. We assume that return on investment provides a metric against which overhead and risk can be evaluated. For example, in Scenario 4 (Table 4), at \$50 ODT^{-1}, a contractor would receive an average return of 32.6% on his production costs when producing a total of 267,552 tonnes. If this average return is inadequate to cover overhead and any risk premium, then the contractor would avoid the least profitable parcels/landings, increasing the average return on production costs but reducing quantity supplied to some lesser amount. The maximum production to just achieve an investment return equal to a given overhead and risk premium can be calculated under a revised objective function. A sensitivity analysis was conducted where we assumed that risk and overhead could be accounted for as a percentage of the total costs. In scenario 4, if overhead is 10% of total costs the average return would be 22.6% at \$50 ODT^{-1} and 248,018.6 tonnes would be supplied. If we assume overhead was 20% of total costs, 204,251 tonnes would be supplied at \$50 ODT^{-1} and average returns would be 16.1%.

Figure 3. Supply curves of juniper biomass for each scenario. Scenario 1 is *Non-Coordinated Profit Maximization,* Scenario 2 is *Coordinated Profit Maximizing Harvest Model,* Scenario 3 is *Rangeland Productivity Improvement,* and Scenario 4 is *Coordinated Harvest + Rangeland Improvement.*

Table 5. Supply Scenarios at Specific Unit Price Points, Average % of parcels harvested,

4. Discussion

This study serves as a benchmark in establishing a range of prices that would signal a ready supply of juniper for a biofuel industry. It also explores the impact on costs of landowner coordination, benefits of vertical integration or cost-sharing, and accounts for external benefits derived from juniper removal. Due to the absence of prior studies attempting to estimate the extraction, processing, and transporting costs of western juniper, a direct comparison for this source of biomass cannot be made at this time. Canadian forest residues have been estimated to be approximately \$41 US ODT^{-1} on average for on-site material before transport (Yemshanov 2014). This operation included pre-piling, loading and chipping. In contrast, this paper estimates costs for felling and gathering a finished chipped and cleaned product that is delivered to the plant.

The viability of a market for biomass depends in part on the prices of substitutes such as fossil fuels. According to the USDA Forest Products Laboratory, a metric ton of oven dry wood contains approximately 19 million Btu. This is equivalent to the energy in 18,500 cubic feet of natural gas (USDA 2004). From 1997 to 2013 the yearly average price of natural gas has fluctuated between \$8.86/million Btu and \$2.09/million Btu (US Department of Energy). This implies a price between \$168.34/metric ton and \$39.71/metric ton for dry wood chips to be cost competitive. When fossil fuel prices are high, juniper biomass can be a cost effective substitute. Low fossil fuel prices would require firms engaged in juniper harvest to develop a business model that capitalizes on the positive externalities associated with juniper removal as well as concentrating on juniper supplies closest to the road and closest to the facility.

The Renewable Energy Portfolio standards and the 10-Year Energy Action Plan of Oregon stress that major utility providers in the state must supply 25% of retail electricity from renewable resources by 2025 (Kitzhaber 2012). Western juniper has been considered to be a promising primary feedstock source for an incipient local market (Oregon Best 2012). Western juniper is the second largest potential source of available biomass in the state (Bowyer et al. 2006). Other sources of biomass present in the study area are agricultural, mill, commercial timber and thinning, and urban waste residues. The timing of the prices and quantities of other available feedstocks will impact the quantity of juniper that would be supplied in an input market for biofuel production.

The closest substitute in terms of cellulosic material is logging residue. According to the Timber Product Output Reports provided by the U.S Forest Service, for the combined counties of Wheeler, Wasco, Jefferson, Crook, and Deschutes, in 2012, there were 189,723 m^3 produced in softwood logging residues (USDA Forest Service 2012). This study estimates that there are 693,763 m^3 of accessible juniper bole wood from private rangeland and given the assumptions in this study, this operation could produce approximately 99,109 $m^3\ yr^{-1}$. This quantity of juniper may serve as a supplement to forest residues from the region, but woody debris produced as an unwanted byproduct of commercial logging will be a cheaper feedstock than this available source of western juniper from private rangelands.

The scale of a torrefaction plant discussed for development in Prineville is planned to produce 36,290 tonnes yr^{-1} (Simet 2012). This pyrolysis technology bakes off volatiles that result in a weight reduction of the original inputs by approximately 20% when operating with optimal conditions, which would require approximately 45,360 ODT yr^{-1} in raw juniper (Shah et al. 2011). When considering only this one source of juniper as the primary feedstock input, the stock would last for nearly 6.5 years. The estimated life of the torrefaction capital is 30 years (Shah et al. 2011). The rate at which juniper is removed from the landscape will be dependent on the price that is offered for delivered chips, higher prices will lead to faster depletion of juniper biomass on the landscape

A government intervention predicated by the failure of a nascent market for biofuel feedstocks may be justified. When considering that western juniper is the second largest source of biomass and that Oregon has set alternative fuels standards goals, creating programs to stimulate the production of juniper from both private and public lands may serve the social welfare of the region in multi-dimensional ways.

The growth rate of juniper was not taken into consideration in this study, height growth of juniper is reported to be 8.9 to 16.8 centimeters annually for dominant trees (Miller et al. 2005). The qualifier of “renewable sources” for the state’s goal of meeting 25% of electricity demand may not include the juniper harvested in this cost study, since grazing improvements were accounted for in perpetuity. Within the context of this study, juniper has been considered non-renewable in that restocking intervals were not assessed and future land-use was intended to shift to intensify grazing when the conditions were favorable. Western juniper as a “renewable” resource in the sense that rangeland owners would produce both juniper and livestock in the long run has not been tested here. This study also assumes that if it is currently available that it is appropriate to harvest and does not take into account its value in providing ecosystem health or sustainability.

If a biofuel industry did develop and created a stable demand for feedstocks, there may be price levels at which quantities of juniper, supplied by private lands, could be viable when coordinating the movement of machinery and taking into account the externalities of removal.

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