Design and Objectives of FTM–West Model

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Abstract—*The FTM–West ("fuel treatment market" model for U.S. West) is a dynamic partial market equilibrium model of regional softwood timber and wood product markets, designed to project future market impacts of expanded fuel treatment programs that remove trees to reduce fire hazard on forestlands in the U.S. West. The model solves sequentially the annual equilibria in wood markets from 1997 to 2004 and projects annual equilibria from 2005 to 2020 using detailed assumptions about future thinning programs and market trends. FTM–West was designed specifically to account for economic complexities that stem from unconventional size distributions of trees and logs removed in thinning operations (compared with conventional timber supply in the West). Tree size directly influences market value and harvest cost per unit volume of wood; log size influences product yield, production capacity, and processing costs at sawmills and plywood mills. FTM–West provides a tool to evaluate future market scenarios for large-scale fuel treatment programs with various thinning regimes that may have varying costs and yield wood with divergent size class distributions. The model provides a capability to analyze and project how much harvestable wood the markets can absorb from thinning programs over time and the regional timber price and timber harvest impacts of expanded thinning under various assumptions about fuel treatment program subsidy or administrative costs, variations in thinning regime, or alternative projections of future product demands across the spectrum of products ranging from wood fuel to lumber, plywood, and wood fiber products.*

Introduction

Decades of fire suppression, reduced timber harvests on public lands since the 1980s, and a build-up of standing timber inventories in fire-prone forested regions of the western United States have created conditions susceptible to catastrophic wildfires. Expanded programs of systematic stand density reduction through mechanical thinning on public lands may reduce fuel build-up. Timber market consequences of such programs depend on the scale of program and the type of treatment regime. This paper describes the design and objectives of an economic model that can project timber market impacts of expanded fuel treatment programs in the U.S. West.

The "fuel treatment market" model for the U.S. West (FTM–West) employs the Price Endogenous Linear Programming System (PELPS). PELPS is a general economic modeling system developed originally at the University of Wisconsin (Gilless and Buongiorno 1985, Calmels and others 1990, Zhang and others 1993) and more recently modified for applications at the Forest Products Laboratory (Lebow and others 2003). PELPS-based models employ the technique of spatial equilibrium modeling (Samuelson 1952), with periodic (for example, annual) market equilibrium solutions obtained by economic optimization. Solutions are derived by maximization of consumer and producer surplus, subject to temporal production capacity

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constraints, transportation and production costs, and price-responsive raw material supply curves and product demand curves, all of which can be programmed realistically to shift over time and respond to endogenous shifts in market conditions. FTM–West employs the FPL version of PELPS (called FPL–PELPS), Lebow and others (2003) and earlier PELPS publications provide further mathematical details about the modeling system. PELPS has been used fairly widely for partial market equilibrium models of timber and forest products for many years (for example, Buongiorno and others 2003, Zhang and others 1996, ITTO 1993).

Structure of FTM–West

Forest sector market models commonly include structural features of wood product markets, such as a regional market structure with regional product demand curves, regional timber supply curves, interregional transportation costs, and regional production capacities and manufacturing costs. Those general structural features were included also in FTM–West. In addition, FTM–West was designed with other features to account for economic complexities that can arise with utilization of wood from fuel treatment programs, which may have a more divergent distribution of volume by tree size class than does conventional timber supply (for example, wood from fuel treatments may have a larger fraction of volume in smaller trees than conventional timber supply).

General Design Features

Among general design features, FTM–West included demands for more than a dozen forest product commodities encompassing the full spectrum of forest products produced from softwood timber in the U.S. West, three product demand regions, eight production or supply regions, and estimated wood supplies from conventional timber supply sources and from future fuel treatment programs (assumed to be primarily softwoods). Table 1 summarizes the regional and commodity structure of the model.

The model included demand only for forest products produced from softwood timber in the U.S. West, a partial representation of total U.S. and global demands for forest products. Fairly simple demand curves were specified in the model based on an assumption that demands for all products are inelastic (price elasticity of demand ranged from –0.3 to –0.8 among the various products). Aggregate demand quantities for each product were equated to product output data for the U.S. West in the base year (1997) and proportioned to each of the three product demand regions using estimates of regional shipments

Table 1—Regional and commodity structure of FTM–West model.

Supply/production regions	Demand regions	Demand commodities
Coast PNW (OR, WA)	U.S. West	Softwood lumber & boards
Eastern Washington	U.S. East	Softwood plywood
Eastern Oregon	Export market	Poles & posts
California		Paper (five grades)
Idaho	*Supply commodities*	Paperboard (three grades)
Montana	“Pines”	Market pulp
Wyoming–South Dakota	“Non-Pines”	Hardboard
Four-Corners (UT, CO, AZ, NM)	(trees, logs, chips)	Fuelwood

from the West. Product output was based on data published by industry associations, such as WWPA (various years) for lumber, AF&PA (2005) for pulp and paper, and APA–The Engineered Wood Association (various years) for plywood. FTM–West was designed to derive annual market equilibria sequentially over a 24-year period, 1997 to 2020, which permitted testing and calibration of model solutions against overlapping historical data (to 2004). Demand curves were shifted each year based on historical shifts in production in the U.S. West (1997 to 2004), and the model was programmed with a set of assumed future growth rates in regional demand (2005 to 2020) for each forest product commodity. Demand growth rate assumptions matched recent Forest Service Resources Planning Act (RPA) Assessment projections (2005 draft RPA timber assessment report).

Similarly, simple supply curves were used to model conventional softwood timber supply in each of the eight supply regions, while exogenous estimates of wood supply from treatment programs (upper bounds on harvest quantity and harvest costs) were introduced as policy or program variables. Estimates of wood supply from fuel treatment programs were obtained from the Fuel Treatment Evaluator, FTE v. 3.0 (Skog and others 2005). Most conventional timber supply in the U.S. West is currently obtained from timber harvest on state and private forestlands, subjected mainly to even-aged timber management. Thus, inelastic supply curves were used for conventional timber supply (with an assumed price elasticity of 0.7). Conventional timber supply curves were programmed to shift over time in direct proportion (1:1 ratio) to net growth in softwood timber inventory volumes on state and private timberland within each supply region. Annual net growth in state and private timber inventories are computed in the model by deducting from standing timber inventories the harvest volumes from the preceding year and adding timber volume growth based on recent growth rates in each region (Smith and others 2004). Thus, FTM–West incorporated techniques similar to those used in the Forest Service RPA Assessment to model conventional timber supply (that is, inelastic supply curves shifted over time in proportion to projected net growth in timber inventories).

In addition to supply and demand curves, FTM–West incorporated estimates of manufacturing capacities for the various products in each of eight production regions, manufacturing cost data, and transportation cost data (for wood raw material and product shipments). A feature of PELPS is that production capacities shift over time in response to projected market conditions, and in FTM–West we used a representation of Tobin's *q* model to project regional capacity change as a function of the ratio of shadow price (or value) of production capacity to cost of new capacity (Lebow and others 2003).

Structural Complexities in Wood Utilization

Beyond general elements of model structure, FTM–West incorporated some unique features to account for economic complexities that were known to be associated with utilization of wood from fuel treatments. Specifically, it was known that the size-class distribution of wood harvest (the distribution of wood volumes by tree diameter class) may be significantly different for wood removed in fuel treatments than for conventional timber supply. Also, it is fairly well known that timber market value and harvest costs per unit volume are highly dependent on tree size class or diameter, whereas mill production capacity, processing costs, and product yields also vary with log diameter, particularly at lumber mills and plywood mills.

Divergent Sizes of Trees and Logs—In recognition of divergent size classes of trees harvested, both the conventional timber harvest and the exogenously specified wood harvest from fuel treatments were modeled in FTM–West by 2-inch (5-cm) diameter classes, ranging from trees <5 inches d.b.h (diameter at breast height) to trees >15 inches d.b.h. Thus, all wood supply is disaggregated into seven tree size classes, each of which can assume a unique market value in the FTM–West model. Furthermore, each tree size class yields different proportions of logs (by 2-inch log size class) along with variable quantities of wood chip raw materials. Estimates of actual log and chip volume yields were derived for each tree size class and for each of the eight supply regions based on recovery data from regional utilization studies conducted at the Forest Service Pacific Northwest (PNW) Research Station (compiled from mill studies by Dennis Dykstra, PNW Station).

Figure 1 illustrates divergent distributions of harvest volume by tree size class as estimated for conventional timber harvest in the U.S. West (in 1997) and for two fuel treatment thinning program regimes (derived from the FTE program; Skog and others 2005). Both the even-aged TFB (thin-from-below) treatment regime and the uneven-aged SDI (stand density index) treatment regime yielded proportionately more volume in smaller trees (size classes less than 9 inches d.b.h.) than did conventional timber harvest, but the SDI treatment also yielded more volume in larger trees (>15 inches d.b.h.).

Figure 2 illustrates the West-wide average log and chip recovery potential from each tree size class (averages for all eight regions in FTM–West). In general, smaller trees can yield only small logs and a high proportion of volume in wood chips, whereas bigger trees can yield more volume in larger logs (which have generally higher value) and a smaller proportion of volume as chips.

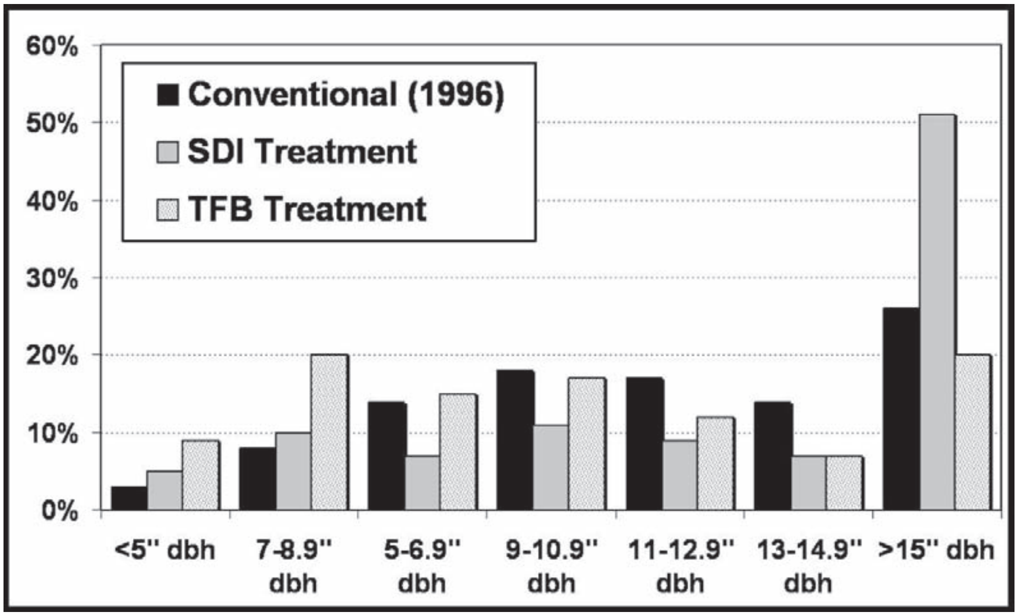

Figure 1—Estimated volume distributions by tree size class for conventional timber harvest and for wood from fuel treatment regimes on federal lands in U.S. West.

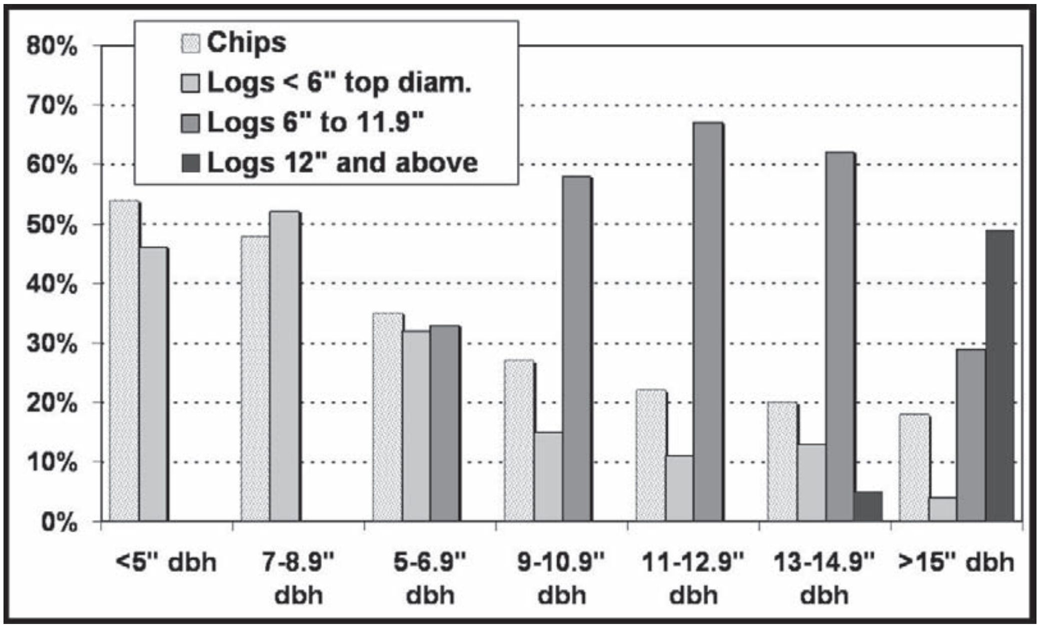

Figure 2—West-wide average log and chip recovery potential (percentages of cubic wood volume recoverable as chips and logs of various sizes) for different tree diameter classes.

Variable Stumpage Values and Variable Harvesting Costs—Harvesting costs per unit of wood volume vary with tree size class due to efficiencies gained in harvesting larger trees with more wood volume per tree or per log harvested. Thus, in addition to modeling wood supply in FTM–West by size class of trees and logs, we used harvest cost models to estimate harvesting costs for each tree size class. Harvesting costs for wood removed in fuel treatments were estimated by the FTE program (Skog and others 2005) using the calculation routine from *My Fuel Treatment Planner* (Biesecker and Fight 2005). Timber harvesting costs for conventional timber supply were estimated by tree diameter class using a conventional timber harvest cost model by Keegan and others (2002).

For the simulated fuel treatment programs, we adopted a policy assumption that fuel treatment managers on federal lands would require removal of all tree size classes marked for thinning, based on an assumption that fuel treatment policies would not allow "high-grading" or just the removal of bigger and more valuable trees. Under that policy assumption, the harvesting and transportation costs applied to all wood from fuel treatments are the volume-weighted average costs across all tree size classes. Note that average costs for fuel treatments (across all size classes) were estimated to be higher than conventional timber harvesting and transport costs in the West.

Figure 3 shows our West-wide averages of wood harvesting costs, wood transport costs to mill, and stumpage costs in dollars per thousand cubic feet (MCF) as assumed or as estimated in the FTM–West model. Costs for conventional timber supply are differentiated by tree diameter class, with notably higher estimated stumpage values for larger trees (2005 equilibrium values).

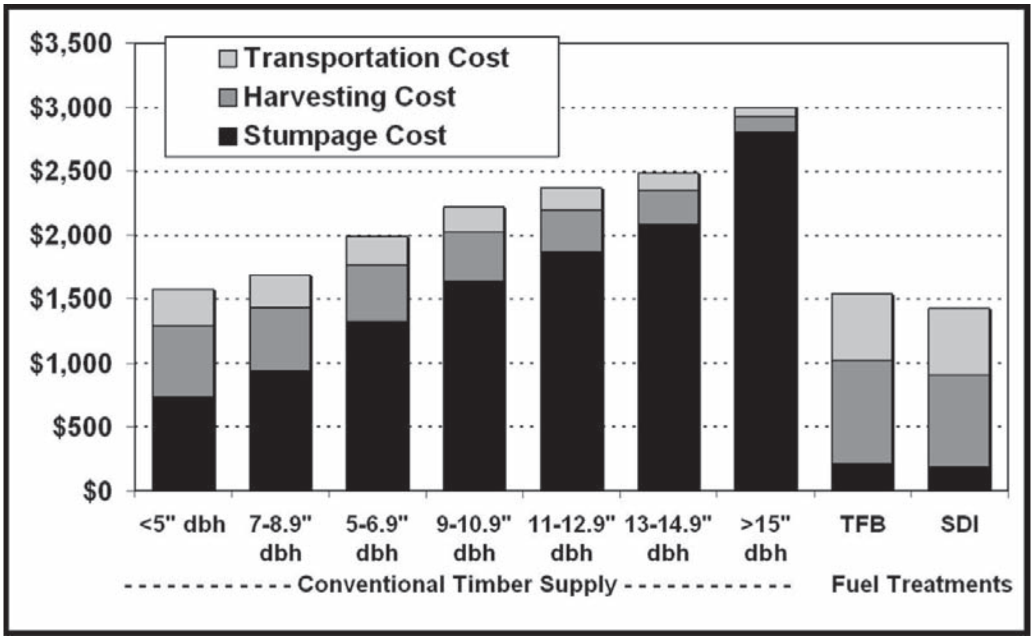

Figure 3—West-wide averages of 2005 delivered wood costs ($/thousand cubic feet) by tree diameter class for conventional timber harvest and wood from fuel treatments, including stumpage cost (2005 equilibrium values computed by FTM–West), harvesting cost, and transportation cost.

In our fuel treatment program scenarios we assumed a hypothetical harvest fee (equivalent to stumpage fee) of $500 per acre, representing a nominal fee for administrative costs. That fee translates to $214/MCF harvested for the TFB thinning program and $188/MCF for the SDI program.

As illustrated in figure 3, the assumed harvest fees (stumpage costs) for the hypothetical fuel treatment programs are considerably lower than the estimated stumpage market values for conventional timber supply in the region, but the estimated harvest and transportation costs for the fuel treatments are considerably higher than those for the conventional timber supply. In essence, we assumed that the hypothetical fuel treatment programs would offer wood to the market at low stumpage fees that would compensate somewhat for the higher harvest and transport costs of fuel treatments. This is purely a hypothetical assumption, and future fuel treatment programs might potentially charge higher or lower fees. Note also that harvest and transportation costs shown here are averages that include costs for both logs and chips delivered to mills.

Variable Product Yields and Variable Sawmilling Capacity—Sawmill capacities are generally constrained by primary saw rigs that break down logs at the front end of sawmills. Primary breakdown saws (or "head rigs") are typically designed to process logs within certain size ranges, some designed to process small logs and some designed to process large logs. Small log mills run logs end-to-end at fairly constant speed, and within a feasible range of equipment design, a larger log yields more product because each cut generates more volume (Fight 2002). In contrast, large log mills may not process logs in one pass but may require multiple passes before logs are sufficiently broken down to permit further processing, which results in unproductive dead time between passes. Furthermore, the larger cross-sectional areas of cuts usually require a slower feed rate with large logs. Thus, effective lineal throughput of logs at large log mills is less than that of small log mills, but the greater volume of wood in each lineal foot more than compensates for the slower feed rate.

In general, sawmill output capacity is determined by (1) the lineal feet of logs that the sawmill is capable of processing in a given amount of time (throughput), (2) the volume of wood contained in each lineal foot of log throughput, and (3) the lumber recovery factor (LRF), which measures yield of lumber in board feet from each cubic foot of log throughput. However, parameters (2) and (3) are strongly influenced by log diameter, and thus lumber output capacity of sawmills varies with the size of log inputs. Product recovery per cubic foot of log input for both lumber and plywood generally increases with log size. Figure 4 is a plot of estimated lumber recovery (in board feet) and plywood recovery (in square feet) per cubic foot of log input by log diameter as estimated for the FTM–West model (Williston 1981).

Sawmill industry mill capacities are conventionally reported in board feet of lumber output rather than lineal feet of log throughput (for example, see Spelter and Alderman 2005). To estimate equivalent sawmill capacities in lineal feet of log throughput, we started by obtaining wood consumption data by log size, available for the states of Washington (Larsen and Aust 2000) and Oregon (Ward and others 2000). In each state the volumes of logs processed by sawmills, expressed in board feet, were provided for four log size classes, as shown for the state of Washington in table 2, row 1.

We then estimated a corresponding distribution of tree harvest volume by tree diameter class (d.b.h.) that would produce a mix of logs (table 2, row 2) exactly matching the actual survey data on log size distribution (table 2, row 1). To do this, we started with data on log recovery volumes from

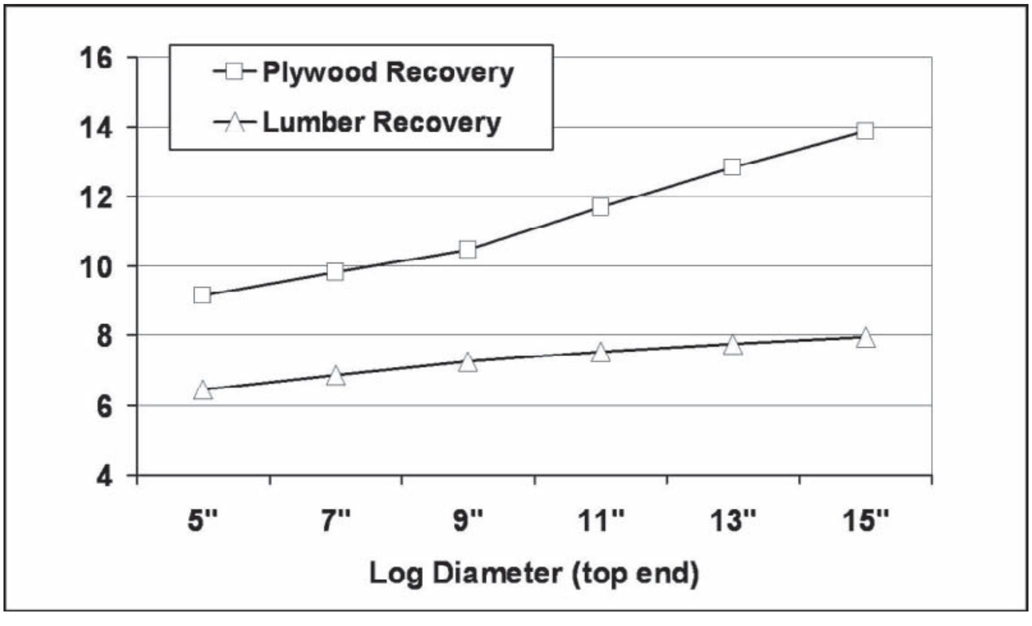

Figure 4—Estimated lumber recovery (board feet) and plywood recovery (square feet) per cubic foot of wood input by log diameter.

Table 2—Log volumes in coastal Washington.

Log diameter class (top end diameter) (inches)	<5	5–10	11–20	21+	Totals
Log volumes (log scale), actual survey data (million board feet)	124.4	908.8	812.0	137.4	1982.7
Log volumes derived from assumed tree harvest (million board feet)	124.5	908.8	812.0	137.4	1982.7
Derived lineal feet of logs (millions)	170.2	541.1	127.2	6.1	844.6
Average cubic feet per lineal foot	0.164	0.457	1.345	3.447	0.553
Derived cubic feet of logs (millions)	27.9	247.4	171.0	21.2	467.4
Average board feet (log scale) per cubic foot	4.46	3.67	4.75	6.49	

field studies conducted over the years at the Pacific Northwest Research Station, as compiled and analyzed by Dennis Dykstra. By an iterative process, we varied the numbers of trees within each tree diameter class until the derived log volumes matched the survey data (table 2, row 2). Then, multiplying numbers of trees by lineal feet of logs from each tree gave derived estimates of lineal log throughput consistent with reported log volumes (table 2, row 3). Regional industry throughput capacity in lineal feet was derived by dividing the estimated lineal throughput by the observed regional capacity utilization ratio (derived from WWPA lumber output data and capacity data from Spelter and Alderman 2005) Thus, we obtained estimates of lineal log throughput capacities at sawmills in western states and FTM–West regions that were equivalent to lumber output capacity in those states and regions. Similarly, multiplying the number of logs by the cubic volume of each log produces estimates of the equivalent cubic foot volumes of mill throughput (table 2, row 5).

To model sawmill capacity in relation to log size, we had to estimate the relationship between lumber output and log size for a given regional log throughput capacity. In other words, we assumed that sawmill capacity is constrained primarily by the lineal log throughput capacity of mill head rigs, but variation in log size can result in marginal shifts in lumber output capacity. Again, for each log size, two variables connect log throughput to equivalent board feet of lumber output: cubic volume of wood in an average lineal foot of log throughput (what we term the V factor) and lumber recovery factor (LRF), the board feet of lumber yielded by a cubic foot of log throughput. Given industry throughput capacity in lineal feet, along with the V and LRF factors, the theoretical board foot capacity for each log size class can be determined. However, portraying lineal throughput capacity as invariant with respect to log size is unrealistic. As logs get bigger, at some point the log breakdown requires multiple passes through the head saw and/or feed speeds must be decreased (Williston 1976). Because we do not have mill capacities by feed speed limits, we approximated this aspect of sawmilling by introducing an arbitrary log speed adjustment factor, effectively speeding processing up for smaller logs and slowing it down for larger logs. This adjustment resulted in a realistic representation of how sawmill throughput would respond to changing log diameters and produced throughput capacities from which board foot capacities were derived by multiplying by the V and LRF factors, as shown in table 3.

Table 3—Board foot lumber output capacity as a function of log size for given log throughput capacity (lineal feet of log throughput).

Log size class (inches)	Capacity (lin. ft)	Adjustment for log speed (%)	Adj. cap. (lin. ft)	V	LRF	Capacity (board ft)
<4	844.6	73	1,461	0.15	6.33	1,387
4–5.9	844.6	52	1,284	0.27	6.44	2,233
6–7.9	844.6	24	1,047	0.51	6.87	3,668
8–9.9	844.6	7	904	0.65	7.25	4,260
10–11.9	844.6	–6	794	0.91	7.54	5,448
12–13.9	844.6	–15	718	1.30	7.77	7,252
>14	844.6	–32	574	2.52	8.20	11,861

It is self-evident that the V factor (cubic volume per lineal foot of log throughput) increases with log size because the wood volume in a lineal foot increases by the diameter of the log squared. The LRF also increases because the share of edgings and slabs becomes a smaller fraction of total volume as logs increase in size (fig. 1).

Variable Manufacturing Costs—In a similar vein, the V and LRF factors affect non-wood manufacturing costs. A mill's labor costs and capital costs, for example, are invariant with respect to the size of a log that is momentarily being processed, and thus they are marginally fixed costs relative to log throughput but variable with respect to product output. Varying log size marginally affects lumber output, and thus fixed costs will be written off against varying volumes of product output. Thus, manufacturing costs per board foot of lumber output vary in FTM–West by log diameter class.

To estimate how manufacturing costs vary with log size class we first developed estimates for each region of average industry non-wood costs (labor, energy, materials, supplies, overhead, and depreciation) per unit of mill output. Multiplying the unit cost estimates by the base year output gave the total dollar value of non-wood manufacturing costs for each region. Given estimated relationships between output capacity and log size, as derived above for each region, we calculated the theoretical manufacturing costs for each log size at a constant log throughput volume as our first approximation of unit costs by log size, which exhibit a pronounced inverse relationship to log diameter (as shown by the "constant throughput" relationship in figure 2). However, again, it would be unrealistic to assume that lineal log throughput speed could remain constant with varying log diameter, so we applied again the log speed adjustment (table 2) to reflect accelerated throughput with smaller logs and slower throughput with larger logs. The result is the relationship shown as the "variable throughput" cost curve in figure 5, which we used to model lumber manufacturing costs by log diameter in FTM–West. Despite the log speed adjustment, there is a big cost difference between processing small logs and large logs.

Plywood manufacturing capacity, manufacturing costs, and product recovery are modeled in an identical manner, using the same V factors and replacing LRF by the plywood recovery factor, whose behavior is identical to the LRF for the same basic reasons (fig. 4).

Finally, as noted previously, regional production capacities in the FTM–West model will shift over the projection period from 2005 to 2020 in response to

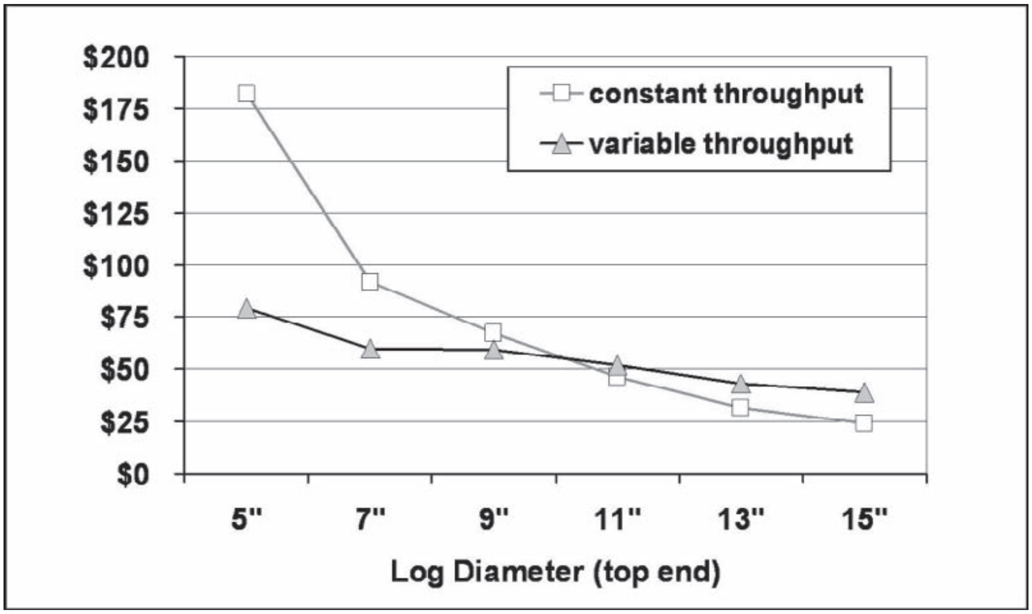

Figure 5—Non-wood lumber manufacturing costs ($/thousand board feet) with constant log throughput and variable-speed log throughput assumptions.

projected economic profitability of investments (Tobin's *q* ratio), simulating long-run capital investment responses to economic opportunities. In scenarios that introduce increased supply of wood from fuel treatment programs, we found that the model responds with capacity expansion, increased regional wood harvest, and displacement of conventional timber harvest by wood from fuel treatments. However, treatment regimes that introduce marginally higher proportions of small-diameter wood than conventional timber harvest will also marginally offset regional production capacities, reduce average product recovery, and increase manufacturing costs for lumber and plywood. Those impacts affect the producer surplus and consumer surplus consequences of fuel treatment programs. Net market welfare impacts of alternative treatment regimes are described in a companion paper in these proceedings (Kramp and Ince 2006).

Summary

The development of FTM–West provided a tool to evaluate future market scenarios for large-scale fuel treatment programs with various thinning regimes that may have varying costs and may yield wood with divergent size class distributions. It also provided a capability to analyze and project how much harvestable wood the markets can absorb from thinning programs over time and the regional timber price and timber harvest impacts of expanded thinning under various assumptions about fuel treatment program subsidy or administrative costs, variations in thinning regime, or alternative projections of future product demands across the spectrum of products ranging from wood fuel to lumber, plywood, and wood fiber products.

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