Supplementary Material

S1. Harvest Equipment Productivity Model Coefficients

S1.1. Stemwise Cycle Times: Feller-Buncher, Harvester, Chainsaw, Processor, and Loader Productivity

Our literature survey (Section 2.1) suggests a linear increase in felling time with tree size [22,41,42] with a quadratic term for bucking larger stems [29,37,47]. It appears plausible larger machines encounter the quadratic term at larger merchantable stem volumes (b_3, Equation (1)) and have cycle times which increase less rapidly with stem size (smaller values of b_1 and b_2, Equation (1)) [26,47]. Since relatively few studies report mean tree volumes greater than 0.6 m^3 it appears that the ability to detect a quadratic response may be restricted by available data and possibly also by evaluating regressions only with $b_3 = 0$. While these limitations and uncertainties suggest further study of cycle time model forms may prove valuable, within the scope of this study it appears Equation (1) is the most readily parameterizable form currently available. Based on our survey of manufacturer specifications (Section S4), we hypothesize larger harvesters' tendency to shorter cycle times on larger stems results from greater boom or crane strength and increased stability. This implies eight-wheel harvesters may, in some cases, have shorter cycle times than tracked harvesters due to longer wheelbases and balanced bogies. But it also may be the case a tracked base is needed for feller-bunchers or harvesters to meet boom lift and swing torque requirements when stems are sufficiently large. Low angle slopes and compacted road surfaces likely increase stability, presumably favoring shorter processor and loader cycle times.

Several studies included move times in their cycle time definitions [22,29,37,42,49,78] but no study reported move times separately from b_0 in Equation (1). Move time can approach one fifth of cycle times [22] and the move distance per tree harvested very likely increases as fewer trees are felled per hectare. Nurminen et al. [29] found harvester cycle times were longer in thinning than clearfelling, in part due to operators choosing lower movement speeds to reduce damage to retained trees, and lower stand densities may be associated with increased cycle times due to greater amounts of brush [40]. Additionally, the amount of time processors and loaders spend moving is presumably dependent on roadside and, when applicable, landing geometry. Due to this range of confounding factors, we concluded we could not reliably extract a movement term from the available models and therefore treated Equation (1)'s movement term as implicit in its coefficients b_{0-3}. While we do not consider thinning intensities below 20% in this study, we caution this approach to movement times may overestimate productivity when relatively few trees are harvested.

We reviewed all of the feller-buncher, harvester, chainsaw, and processor models we identified as valid or were able to correct (Section 2.1) by plotting cycle time or productivity, as applicable, as a function of stem size within the range of the source's dataset. We then generated central parameter estimates for Table S1 after adjusting for study to study differences in published cycle times and considering changes in harvest equipment over time [29]. We back tested the resulting parameterizations within the fitting ranges of published productivity models and checked that the resulting productivity curves maintained plausible levels and shapes for stem sizes up to 15 m^3. The parameterization was then widened produce the intervals in Table S1. If the reader is feeling generous, we suggest this approach approximates the expert opinion method for ascertaining model uncertainty described by Uusitalo et al. [67]. However, we caution the sources reviewed report productivity differences of up to an order of magnitude and the number of machine and harvest unit interactions which have been studied appears small compared to the possible range of variability. While we have attempted to balance variation among sources, we feel our approach is best interpreted as generating a nominal model which is likely to benefit from refinement based on machine, harvest unit, and region specific factors.

Table S1. Cycle time coefficients used as uninformative Bayesian priors with Equation (1) in this study to predict mean stemwise cycle times in delay-free productive seconds as a function of stem size. Because harvester size affects productivity [26] and our stability estimates and tree sizes indicate for a large harvester, we assume a heavy eight-wheel harvester such as a Ponsse Bear with an H8 head or Rottne H21[D]. Since we were unable to locate any models for loaders (Table 1) we assumed a loader productivity of two long log truckloads per hour (Table S6) and did not estimate costs for the harvester-forwarder-loader system of Figure 1.

Machine type	Operations	Equation (1) coefficient ranges for mean delay-free cycle time in seconds							
		b_0	b_1	$b_{2,1}$	$b_{3,1}$	$b_{2,2}$	$b_{3,2}$	b_4	S_t
tracked feller-buncher	fell	14–22	2.7–6.7	0	0	0	0	0.009–0.014	25–35
eight-wheel harvester	fell and buck	22–34	38–48	5–7	1.7–2.1	0	0	0.008–0.012	40–50
tracked harvester	fell and buck	22–34	35–45	2–4	2.0–2.4	2–4	4–6	0.009–0.014	25–35
chainsaw	fell and buck buck	55–75 42–60	90–120 48–60	24–36	0.8–1.2	0	0	0.010–0.015	40–60
tracked processor	buck	15–25	25–35	1–2	2–3	4–5	6–8	n/a	n/a
loader	load	unknown	unknown	0	0	0	0	n/a	n/a

n/a: not applicable. We assumed processors and loaders operated on slopes low enough not to affect cycle times.

Table S2. Cycle time terms used as uninformative Bayesian priors with Equation (2) in this study to predict mean roundtrip cycle times in delay-free productive minutes for machines moving wood from its felling location to a road.

Machine type	Equation (2) terms for mean delay-free cycle time in minutes			
	$\bar{v}_{s,unloaded}$, m min^{-1}	t_{load}, min	$\bar{v}_{s,loaded}$, m min^{-1}	t_{unload}, min
eight-wheel forwarder	60–120 untethered 40–60 tethered	$0.28\frac{P_{l,c}^{0.97\pm10\%}}{\bar{V}_l^{0.60\cdot\pm10\%}} + 0.08\left(\frac{P_{l,c}}{\bar{V}_{l,cd}}\right)^{0.77\pm10\%}$	50–100 untethered 25–60 tethered	$0.46\text{–}\ 0.92\frac{P_{l,c}^{0.62\pm10\%}}{\bar{V}_l^{0.49\pm10\%}}$
grapple yarding	150–184	0.38–0.46	same as unloaded	0.29–0.37
choker yarding	150–184 skyline 35–41 lateral	0.80–0.96 + (0.09–0.13)N_p	same as unloaded	0.36–0.44

$P_{l,c}$ = forwarder load volume in merchantable m^3 as a function of harvested log density $\bar{V}_{l,cd}$, corridor length, the forwarder's slope adjusted load capacity $P_{l,kg}$, and the mean volumetric density (kg m^{-3}), bark fraction (m^3 m^{-3}), and trim fraction (also m^3 m^{-3}) of the logs loaded. $\bar{V}_l$ = mean merchantable volume of logs (m^3) in a forwarder load. $\bar{V}_{l,cd}$ = mean volume of logs for forwarder load per meter of corridor, merchantable m^3 m^{-1}. N_p = number of pieces (logs or trees) yarded in turn.

S1.2. Roundtrip Cycle Times: Forwarder, Yarder, and Log Truck Productivity

We estimated productivity of machines making roundtrip cycles (Tables S2 and S3) using methodology similar to our approach for machines with stemwise cycle times (Section S1.1). Nurminen et al. [29] and Hildt et al. [47] proposed broadly similar models for forwarders. We unify their approaches and adjust our model for consistency with other forwarder cycle time predictions [45,48] (Table S2). In particular, our literature review (Section 2.1) found forwarder productivity both increasing and decreasing with the number of logs loaded per turn. While details are not always clear, this appears to be due to some studies having primarily turns with full forwarder bunks, where a greater number of logs decreases productivity due to a larger number of grapple movements, and other studies having mostly partially full bunks, in which case a greater number of logs increases payload efficiency and productivity.

We resolved this difference in the sign of forwarder payload effects by allowing forwarder payloads to vary. On low angle slopes, the maximum payload weight $P_{l,kg}$ in kilograms is set by the forwarder's design weight limit $P_{design,kg}$. On slopes steeper than about 45–60%, it is likely payload weight is limited by the tractive force F_t (in kN) available from the current soil and surface conditions and the forwarder's engine and tracks. We approximate $P_{l,kg}$ as

$$P_{l,kg} = \min\left(P_{design,kg}, \frac{F_t}{0.009807\sin(\mathrm{atan}(0.01S_{corridor}))} - W_{f,e}\right) \quad \text{(S1)}$$

where $S_{corridor}$ is the slope, in percent, which the forwarder ascends and $W_{f,e}$ is the forwarder's weight when empty, including the weight of add on equipment such as a traction-assist winch and tracks. Observations from harvest contractors in our area suggest forwarder operation at 50–100% of manufacturer specified F_t, depending on soil type and moisture content, which appears sufficient to explain slope related variations in forwarding productivity comparable to those observed for harvesters (Table S1).

In tethered operation, forwarders usually descend harvest corridors empty and then load while ascending towards a road [50]. With short corridors or low densities of logs, the forwarder will reach the top of the corridor before $P_{l,kg}$ is reached, in which case we calculate productivity (in merchantable m^3 PMh$_0^{-1}$) by dividing the total volume of logs loaded (merchantable m^3) by the turn's cycle time (delay-free productive machine hours, PMh$_0$). For corridors with more wood to forward than $P_{l,kg}$ we assume the forwarder fills its bunk starting from the corridor's far end and then returns for however many shorter turns are required to remove all of the merchantable wood from the corridor. In these multi-turn cases we again find productivity from the total volume of logs loaded but divide by the total of all of the turns' individual cycle times.

While finding the most efficient forwarder loading and routing strategy is a spatial optimization problem beyond the scope of this study, we attempt to find the most productive approach within our constraint of a nonspatial tree growth model (Section 2.4). For each of the three primary timber assortments for coast Douglas-fir (*Pseudotsuga menziesii* var *menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)—number 2, 3, and 4 sawlogs, referred to as 2S, 3S, and 4S respectively [79]—we calculate the mean harvested log densities in merchantable m^3 per m^2 of stand area by scaling the individual trees selected for harvest into 2S, 3S, and 4S logs using taper equations [72] and applying growth model expansion factors [71]. Multiplying by corridor width yields the corridor mean log density $\overline{V_{l,cd}}$ (merchantable m^3 corridor m^{-1}) for each assortment and multiplying $\overline{V_{l,cd}}$ by corridor length then provides mean total volume harvested per corridor. We then calculate productivity for 1) forwarding the 2S, 3S, and 4S assortments in separate turns, 2) forwarding 2S and 4S in the same turn and 3S in separate turns, and 3) forwarding all three sorts in the same turn. For turns with a single assortment we use a fixed t_{unload} constant of 0.46, increasing to 0.51–0.64 for two sorts and 0.69–0.92 for three sorts (Table S2) in consideration of the complexity of unloading multiple sorts. We assume the forwarder unloads at roadside each time it reaches the top of a corridor [39], travelling an average 30 m to do so plus an additional 20 m for each additional sort. Finally, we assume the forwarder operator uses whichever of the three loading approaches is most productive and calculate harvest costs on that basis. Most commonly, separate forwarding of each assortment available is chosen. However, turn time differences are often small and loading all assortments simultaneously may be preferred for reducing soil impacts as it minimizes the number of machine passes in a corridor [34].

For cable yarding we assume the same corridor length as for forwarding and a parallel yarding pattern since we assume either an excavator-based yarder (also referred to as a yoader) or a purpose built swing yarder moving logs to roadside. The average yarding distance is therefore half the corridor length and the number of turns required to yard all harvested wood is the total weight of wood harvested divided by the mean turn weight. For excavator-based yarders we use mean turn weights of 1500–1600 kg [51] and assume mean weights of 1925–2075 kg for swing yarders. Yarding productivity (again in merchantable m^3 PMh_0^{-1}) is then the total merchantable volume moved divided by the time taken for all of the turns, similar to forwarders. We use the same approach to calculate the total number of log truck trips required to haul all of the wood to a sawmill but, rather than consider the details of the haul route, abstract it to a nominal three hour roundtrip (Table S3). Since roundtrip haul times in our study area are typically between two and four hours, three hours serves as a representative figure. Variability in the mean haul time, given fixed harvest unit and mill locations, is usually minimal as haul routes are primarily on uncongested, surfaced roads with infrequent snow and ice.

Table S3. Simplified cycle time model used with log trucks.

Log truck type	**terms for mean delay-free cycle time in minutes**		
	roundtrip travel time $t_{roundtrip}$, hours	**t_{load}, min**	**t_{unload}, min**
mule train	2.9–3.1	25–35	20–30
six axle long log		15–20	15–20

Since forwarding, yarding, and trucking are all subject to weight limits (Section S4), productivity of roundtrip cycles increases as bark loss increases the fraction of merchantable stemwood transported per unit weight. Because limited bark loss data is available for coast Douglas-fir [74] and we were unsuccessful in locating bark loss data for western hemlock, we assumed spiked drive wheels in processing heads averaged 30% bark removal when logs of either species were produced by a harvester or processor and that negligible bark loss occurred during falling or chainsaw bucking. Since bark is very likely lost to abrasion during cable yarding [65] we assumed 7.5% bark loss when checking against yarders' maximum payload weights (Table S6) and another 7.5% loss by completion of yarding. Mule trains therefore carried logs retaining 70% of their original bark from cut-to-length systems and, as processing and yarding losses were multiplicative, long log trucks carried logs with 60% of their original bark. We neglected seasonal variation in bark loss [74] and moisture content to constrain this study to mechanical variation in productivity and economic variation in operating costs.

S2. Harvest Equipment Operating and Business Costs

We used an extended version of Miyata's method [66] to estimate differences in operating and business costs across five equipment use profiles: 1) purchase new and trade in at 8000–10,000 operating hours, 2) purchase new and operate to design life (typically taken to be 18,000–20,000 h based on manufacturer information), and 3) purchase used and operate until no longer economic (nominally 25,000 h), 4) an extreme case where all parameters vary in favor of low costs, and 5) a similarly extreme high cost case. We assume the harvesting business is a passthrough tax entity and that profit or revenue taxes are therefore a negligible component of business costs, which is generally the case for businesses filing taxes as S corporations in the United States. We also assume the business takes profit and risk beyond the return on equipment capital considered by Miyata to cover uncertainty in timber sale cruising, variations in operating conditions, productivity differences between equipment operators, and other risks. We used fuel consumption rates indicated by our literature review (Section 2.1), particularly Holzleitner et al. [35], and variation in fuel prices over the last decade [80] adjusted for cardlock purchase of untaxed diesel. Miyata's method also calls for maintenance costs, which we estimated as a function of operating hours from dealer warranty information and approximations of the cost of employing a mechanic.

Because the resulting cost models contain up to 110 parameters per machine, we simplify them by averaging use profiles 1–3 to find central estimates of utilization and operating cost per scheduled machine hour (SMh) and then estimate a likely range of variability from the two extreme cases. These estimates are summarized in Table S4 and the accompanying spreadsheet details the calculations from the 824 input parameters. Since we were able to find only one tether capable machine to include in our pricing dataset (a feller-buncher) we adjusted feller-buncher and tracked harvester pricing for the cost of installing winch assist cable fittings and added the cost of a converted excavator serving as an anchor machine. Due to the size of rainforest Douglas-fir and western hemlock, we assumed upper end pricing for wheeled harvesters and forwarders, included the cost of an add on winch, and adjusted for use of tracks on all eight wheels. Rather than construct a Miyata model for log trucks, we updated the six axle operating costs found by Mason et al. [59] to an estimate of US\$ 95–105 PMh_0^{-1} in 2020 dollars [81] and extrapolated a cost of US\$ 120–130 PMh_0^{-1} for seven axle mule trains.

Table S4. Utilization and operating cost ranges used as uninformative Bayesian priors in estimating harvest cost. We assumed machines operating independently reached their potential utilization and that yarder-processor-loader systems operated at the utilization imposed by whichever machine in the system had the lowest productivity (Section S3). Chainsaw use cases are described in Section S4.

Machine type	Tethering method	Potential utilization, %	Range in operating cost , US\$ SMh^{-1}
eight-wheel harvester	add on winch	77	204–245
eight-wheel forwarder	add on winch	79	182–217
tracked feller-buncher	anchor machine	77	175–210
tracked harvester	anchor machine	77	176–210
anchor machine	not needed	77	64–79
chainsaw by operator	not needed	25	1.90–2.44 + delay
chainsaw bucker	not needed	75	69–89
chainsaw falling crew	not needed	50	107–145
excavator-based yarder	not needed	75	226–269
swing yarder, grapple	not needed	80	324–397
swing yarder, choker	not needed	82	420–512
processor	not needed	89	186–221
loader	not needed	90	155–190

Productive machine hours (PMh_0) are found by multiplying scheduled machine hours (SMh) by utilization.

To find purchase, resale, and salvage values for harvesters, forwarders, feller-bunchers, processors, and loaders we fitted curves to our pricing dataset (Figure S1), assuming no machine sold above asking price and no machine sold below 75% of asking. We also assumed chainsaw equipment had negligible salvage value and the pricing curves for eight-wheel harvesters and tracked feller-bunchers could be extrapolated to 25,000 h. Insufficient information was available to form price curves for yarders. For excavator-based yarders we therefore estimated the cost of yarder conversion and assumed depreciation comparable to a processor. For swing yarders we used the price reported by Mattioda [39] and assumed a 20 year operating life. The relationship between operating meter hours and productive machine hours is uncertain [82] but may be converging towards PMh_{15} (productive machine hours including delays up to 15 min) over time [83,84]. Absent more specific information, we assumed meter hours were PMh_{15} h and approximated delay-free productive machine hours (PMh_0) as PMh_0 = max(utilization, 0.9) PMh_{15} [84] when calculating depreciation rates and maintenance costs using Miyata's model and also when converting fuel consumption from a PMh_{15} basis [35] to a PMh_0 basis.

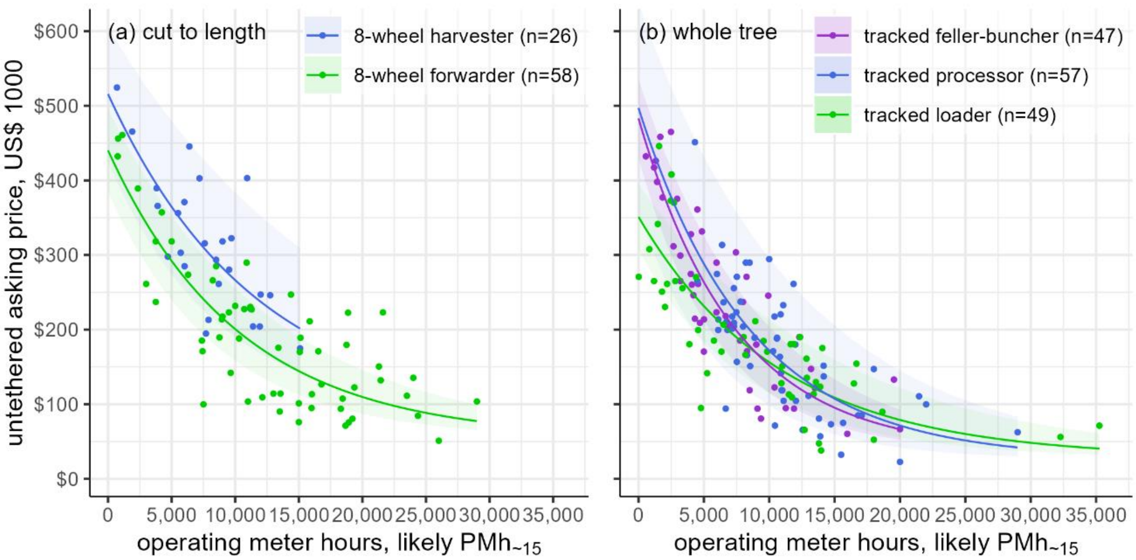

Figure S1. Asking prices in United States dollars for eight-wheel, double bogie harvesters and forwarders used in cut-to-length systems (left) and the feller-bunchers, processors, and loaders used in whole tree cable yarding systems (right) based as a function of operating hours logged by the machine. Price curves are regressions of the form $b_0 + b_1e^{-b_2\ \text{hours}}$, with b_0 adjusted for survivorship bias to account for machines parted out rather than offered for resale at high operating hours. Shading indicates the 95% confidence interval for the regressions. Prices were observed in 2021 dollars and adjusted to 2020 dollars using preliminary producer price index data through October 2021 [81].

S3. Harvest System Costs: Utilization of Coupled Machines and Harvest Related Task Costs

As noted in the main text (Section 2.3), cable yarders, processors, and loaders operate as a coupled group of machines. Since the group's overall productivity cannot exceed the productivity of the least productive machine in it, we estimate the harvest cost for the group by finding each machine's average productivity and assume the two most productive machines reduce their rate of operation to match the slowest machine. Since such slowdowns constitute delays, they reduce the more productive machines' utilization and have the effect of requiring all three machines be scheduled for the same number of hours as the least productive machine. Compared to independent operation, this increases the number of scheduled machine hours and therefore increases the harvest system's cost. It is most likely the yarder has the lowest average productivity but, with short enough yarding distances, productivity will be constrained by the processor or loader.

Also, as noted in Section 2.3, we include harvest related tasks (Table S5) within our definition of harvest cost. To avoid confounding the variability in harvest system costs with the variability among harvest units, we hold these unit related costs constant. The resulting offset term in Equation (3) represents a compromise between accurately representing harvest cost per unit volume (US$ m^{-3}) and capturing total variability of harvest costs.

Table S5. Costs of harvest related tasks. We assumed a 20 ha harvest unit accessed by 20 km of forest roads and that machine move in and out had the same three hour roundtrip travel time as assumed for log hauling. The number of machines moved in and out is the number of machines in the harvest system used plus a bulldozer for roadwork. Cruising, sale, road reopening, brush control, road maintenance, and reforestations cost can vary substantially between harvest units but we attempt to use representative costs. Replanting densities are 990 seedlings ha^{-1} for coast Douglas-fir (*Pseudotsuga menziesii* var *menziesii* (Mirb.) Franco) and 1113 seedlings ha^{-1} for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.).

Task	Cost
timber cruising	US$ 65 ha^{-1}
timber sale administration	US$ 32 ha^{-1}
machine move in	$170 lowboy hour^{-1} in roundtrip travel time between yard and unit plus $20 for loading and unloading per machine moved in
road reopening and adjustment	US$ 50 ha^{-1}
brush control	US$ 45 ha^{-1}
general slash disposal	US$ 0.35 merchantable m^{-3} harvested
yarder landing slash disposal	US$ 0.12 merchantable m^{-3}, if applicable
forest road maintenance	US$ 0.10 km^{-1} merchantable m^{-3}
machine move out	same as move in
site preparation after regeneration harvest	$345 ha^{-1} ($145 ha^{-1} labor, $200 ha^{-1} herbicide)
tree planting labor and seedlings	$383 ha^{-1} labor + $0.50 seedling ha^{-1}
release spray	$275 ha^{-1} ($100 ha^{-1} labor, $175 ha^{-1} herbicide)

We assume reforestation costs are amortized under 26 USC § 194 with a 4% discount rate.

S4. Harvest Equipment Operating Limits: Diameters, Weights, and Chainsaw Assistance of Mechanized Operation

Chainsaws are the only type of equipment considered in this study which is not subject to one or more diameter, weight, or distance limits (Table S6). It follows that, when a tree grows too large to be handled by mechanized equipment, use of a chainsaw becomes necessary to harvest the tree. We consider three chainsaw use cases: 1) the operator of a harvester or feller-buncher performs chainsaw work, 2) a bucker is included in a yarding crew to cut logs from trees too heavy to yard entire [5], and 3) a two person crew fells and bucks large trees left behind by heavy equipment. Since a heavy equipment operator's primary machine is delayed in the first case while chainsaw work is performed, we increase the machine's scheduled hours accordingly and add the cost of operating the chainsaw (Table S4). We assume feller-bunchers are equipped with directional felling heads when tree diameters require and, to the extent possible, heavy equipment operators make two sided cuts with their processing head or directional felling head to fall trees up to their equipment's maximum diameter. In the second and third cases, we assume chainsaw work requires cuts on trees totaling 30 m^2 of basal area per hectare to reach full crew utilization. Below that threshold, we account for move time between trees by reducing utilization linearly from 100% utilization at 30 m^2 ha^{-1} to 0% at 0 m^2 ha^{-1}.

Table S6. Diameter, weight, and extraction distance limits by harvest machine type. Limits are determined primarily by selecting equipment appropriate to the central Pacific Temperate Rainforest from a survey of specifications from 27 equipment manufacturers, which generally favors larger and heavier machines than might be selected for use in regions with smaller trees. Tree species specific diameter limits are determined by comparing processing head cutting diameters, lower knife openings (if applicable), feed roller openings, and upper knife openings to species specific taper equations [72].

Machine type	Operation	Douglas-fir DBH limit, cm	Western hemlock DBH limit, cm	Tree weight limit, kg	Corridor length limit, m
eight-wheel harvester	fell and buck	70	67	by DBH limit	≥ 280 (≥ 500)
	fell	95	88	none	
tracked feller-buncher	fell and bunch	56	54	none	≥ 500
	fell and direct	95	90		
	fell	>115	>115		
tracked harvester	fell and buck	80	78	by DBH limit	≥ 500
	fell	105	98	none	
chainsaw	none	none	none	none	none
eight-wheel forwarder	load and unload	>115	>115	20,000	≥ 280 (≥ 500)
excavator-based yarder	grapple	>115	>115	2750–2900	≥ 500
swing yarder	grapple	>115	>115	3800–4000	≥ 560
	hook with chokers	none	none		
processor	buck	80	78	by DBH limit	none
loader	sort and load	>115	>115	5700–16,000+	none
six axle long log truck	transport	none	none	26,000–26,500	none
seven axle mule train	transport	none	none	28,500–29,000	none

DBH = diameter at breast height (1.37 m). n/a: not applicable. The 29 manufacturers surveyed are Acme, Alpine, Better Weigh Trailers, Cat, ClimbMAX, Doosan, EMS, Falcon, John Deere, Kenworth, Koller, Komatsu, Kone Ketonen, Konrad, Link-Belt, Log Max, Madill, Ponsse, Quadco, Rottne, Satco, Tigercat, TimberMAX, T-Mar, TST, Valentini, Waratah, Whit-Log Trailers.

We note yarder payload efficiency is lower than forwarder and log truck efficiencies. We assume log trucks haul loads at 99% of their weight limit and allow forwarders to reach 100% of rated load when a corridor contains a sufficient volume of logs. For excavator-based grapple yarding we use the 53% payload efficiency suggested by the mean (1550 kg) and maximum (2900 kg) payloads found by Engelbrecht et al. [51]. This higher than the 36 and 44% efficiencies found by Spinelli et al. [53], possibly due to greater line pull being available on the yarders Engelbrecht et al. studied. In lieu of more specific data for swing yarders we assume 50% payload utilization, an increase in maximum payload commensurate with the increase in line pull, and use of a carriage of weight comparable to a grapple carriage in the choker yarding configuration.

S5. Software Used

Source code for this study's calculation of harvest cost and land expectation values, version of Organon, and identification of optimal thinning intensities is available from https://github.com/OSU-MARS/SEEM. We inspected the model equations found in our literature review (Section 2.1), generated Monte Carlo draws and Sobol' quasirandom numbers, and analyzed harvest cost output in R 4.1.2 using RStudio 2021.09.0 and the cowplot 1.1.1, dplyr 1.07, fst 0.9.4, ggplot 3.3.5, ggrepel 0.9.1, grid 4.1.2, magrittr 2.0.1, patchwork 1.1.1, readr 2.0.2, readxl 1.3.1, scales 1.1.1, sensobol 1.1.0, tidyr 1.1.4, and writexl 1.4.0 packages.