Forest Roads from the Perspective of Managerial Accounting—Empirical Evidence from Austria

Philipp Toscani [1,*] **, Walter Sekot** [1] **and Franz Holzleitner** [2]

1   Institute of Agricultural and Forestry Economics, University of Natural Resources and Life Sciences, Feistmantelstraße 4, A-1180 Vienna, Austria; walter.sekot@boku.ac.at
2   Institute of Forest Engineering, University of Natural Resources and Life Sciences, Peter-Jordan-Straße 82, A-1190 Vienna, Austria; franz.holzleitner@boku.ac.at
*   Correspondence: philipp.toscani@boku.ac.at

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Abstract: State-of-the-art forest management requires an adequate opening-up in terms of forest roads. In addition to the increased efficiency of harvesting operations, a higher road density may trigger other positive and negative side-effects. Austria has a long tradition of forestry, and also of monitoring the economic performance of forest enterprises by means of forest accountancy data networks. Using these almost unique preconditions, this research paper approaches the topic of forest roads from a managerial accounting perspective. Based on a specially designed report, the results for the fiscal years 2008–2017 were investigated. On average, Austrian forest enterprises larger than 500 ha report a road density of 50.5 m/ha. The yearly net cost of forest roads, including depreciation and reduction of revenue, is 32.4 €/ha. The pure maintenance cost amounts to 27.9 €/ha on average. The annual investment in forest roads accounts for 9.4 €/ha. Whereas the enterprises' average annual cost of maintenance is 0.63 €/m, the actual maintenance cost of forest roads is 5.6 €/m. To cover the ongoing costs of maintenance, 12.1% of the allowable annual cut is needed. Grouping the analyzed enterprises according to different attributes, namely size of forest land, production conditions, coherence of estate, average slope, and share of forest land requiring cable yarding, showed some statistically significant differences in the maintenance costs of forest roads. In almost all of the tested groupings, significant differences of maintenance costs (expressed as €/ha, €/m³ felling volume, or €/m) were found. However, an initially expected significant correlation between road density and harvesting cost could not be established. The challenges brought about by the trend towards a bioeconomy on the one hand and climate change on the other most likely further enhance the significance of the opening-up of forests and the efficiency of road maintenance.

Keywords: forest roads; harvesting cost; maintenance cost; contribution margin; forest accountancy data network

1. Introduction

Leibundgut [1] has stated that the opening-up of forests in terms of a forest road network is a precondition for state-of-the-art forest management and refined silviculture. In addition to the increased efficiency of harvesting operations, the generally better accessibility of the forest for personnel, material, and equipment eases the need for supervision and helps facilitate silvicultural operations, as well as hunting and all other kinds of activities in the field [2–4]. In spite of the great significance of forest road networks for sustainable forest management, Austrian official statistics end in the mid-1990s. Time series based on information from the forest authorities indicate a decline in road construction starting in the mid-1980s [5–7]. Within the framework of the National Forest Inventory, data on the opening-up of forests was collected for the last time during the period 1992–1996. At this stage,

the average density of forest roads in commercial forests was 44.9 m/ha and significant differences existed between categories of ownership [8]. Skidding trails contributed another 43.9 m/ha to the opening-up of Austrian forests.

The technical aspects of road construction and ecological issues are quite well covered by recent literature [9–32]. In contrast, little is known about the associated economic aspects, apart from some general considerations and concepts related to investment appraisal. The economic advantages of investment in the forest road network are usually considered in terms of a reduction of harvesting costs. Together with the timber prices at roadside for the different assortments, harvesting costs determine the economically recoverable inventory. Thus, the opening-up of forests could lead to a substantial extension of the share of commercial forests, especially in mountainous regions. A positive contribution margin is of the utmost importance for the delimitation of the economically recoverable inventory, along with the final harvest (in terms of stands, individual trees, and also specific assortments such as slash for biomass). It determines the character of thinning operations, either as investments or as sources of cash. As already shown by Rieseneder [33], the return on investments into the opening-up of forests strongly depends on the current road density and the specific building costs. Low forest road densities combined with low construction costs lead to the most profitable investments. As the opening-up of forests progresses towards the individually intended level, the economic focus shifts from investment analysis and the financing of new projects to the costs of road maintenance. This paper aims to expand the empirical knowledge regarding the actual economic characteristics of forest roads through the example of large forest enterprises (> 500 ha) in Austria. For this purpose, we analyze the costs of forest roads and the impact of the opening-up of forests on enterprise profits. We highlight some investment appraisal peculiarities regarding forest roads, summarize specific principles of cost accounting, and discuss the significance of different ratios. Furthermore, differences between the maintenance costs of differently grouped enterprises are investigated statistically.

2. Materials and Methods

In the so-called DACH region (consisting of the German speaking countries Germany (D), Austria (A), Switzerland (CH)), monitoring the profitability of forest enterprises by means of forest accountancy data networks (FANs) dates back to the late 1950s [34,35]. FANs represent a specific approach of empirical economic research, which is methodologically located between questionnaire-based surveys on the one hand and case studies on the other. Although they are neither true statistical samples nor fixed panels, they are most valuable for eliciting detailed socio-economic information and the investigation of respective developments in the sector. Further information concerning this method has been documented by Hyttinen et al. [34] and Toscani and Sekot [35]. Hence, a bulk of empirical data is available, especially in these few countries, providing almost unique preconditions for economic analyses [36]. For our study, we refer to the Austrian FAN (A-FAN) of larger forest enterprises (> 500 ha), which is currently a sample of almost 100 forest enterprises out of a total of about 330, who voluntarily provide access to their managerial accounting on an annual basis [37]. In terms of acreage, the FAN covers more than half of the total area, which in turn accounts for about 25% of Austrian forests. Hence, our results directly pertain to one-eighth of the forest area in Austria, and thereby represent one-quarter of it.

The data frame of the A-FAN is defined in terms of managerial accounting and comprises obligatory and optional elements, in terms of monetary figures and non-monetary information on forest roads, following the specific guidelines [38]. Data on the opening-up of forests and on specific revenues related to forest roads is available from 1997 onwards. Although the individual reports cover all of these, standard reporting of the A-FAN for groupings does not include such detailed information about forest roads. Thus, a special report comprising all available monetary and non-monetary information about forest roads was designed and a time span of 10 fiscal years (2008–2017) was analyzed. The annual spending of forest enterprises on forest roads shows significant fluctuations (2.3–96.5 €/ha—mean value of the lowest and highest 5%) due to impacts such as floods, heavy rainfall, varying periods of frost,

fluctuating harvest volume, as well as liquidity. This implies that an assessment of developments would require much longer time series and would not yet deliver significant results. Consequently, no true panel was required, and all relevant data was included in the investigation. A total of 120 individual enterprises participated in the A-FAN between 2008 and 2017. Missing information about forest road length led to the exclusion of 5 enterprises. The remaining 115 enterprises included in this research (as compared to 74 of a true panel) delivered 975 single-year results due to the individually varying number of periods of participation. The mean values of each enterprise were calculated in terms of weighted averages from the individual observations, i.e., by dividing the sum of cost by the sum of harvest volume ($n = 1$ to 10). Overall results for the 115 analyzed enterprises are presented in terms of weighted averages. To compare different groupings, we refer to median values in order to avoid the impact of outliers. Monetary values in this article are given in Euro (1 EUR = 1.29 USD, average exchange rate 2008–2017 [39]), deflated to 2017 values based on the national consumer price index [40]. Monetary values refer to the felling volume (FV) or allowable cut (AC), which are calculated in m^3 under bark and further noted as €/m^3 FV and €/m^3 AC. A known issue with the A-FAN's data is the non-representativeness of results due to self-selection of the voluntary participants [41]. Although the results derived from the A-FAN are, thus, only indicative, their significance cannot be denied, as they cover approximately 30% of the population in terms of enterprises and 50% in terms of forest land. Further information about methodological limitations and potentials can be found in [34,42–44]. As the A-FAN is not a random sample, the statistical analysis is dominated by descriptive measures. Furthermore, Kruskal–Wallis tests were performed in order to underpin the significance of differences between various groupings of enterprises. Correlations of variables were calculated using Spearman´s rank correlation test, as Shapiro–Wilk tests indicated missing normal distribution of most of the used variables. All statistical data processing was performed using the statistical computing software R [45].

3. Results

According to the A-FAN, the average opening-up of forests by means of forest roads amounts to 50.5 m/ha of commercial forest compared to 41.9 m/ha, as documented by the National Forest Inventory in the period 1992–1996 for enterprises exceeding 200 ha [8]. The recording of the costs of forest roads, differentiated into types of cost and associated revenue, such as subsidies and reimbursements, is obligatory in the A-FAN. A further break down of cost items according to sub-cost centers' "own forest roads", "common property forest roads", and "skidding trails", is recorded on an optional basis only. Both forest roads and skidding trails are permanent elements of the forest road network. Forest roads are typically gravel-paved non-public roads (secondary roads) devoted for use by motor trucks, connecting the primary landings with the public road network (primary roads). Skidding trails are typically built as earth roads without any pavement. On average, 9.0% of the total costs of forest enterprises pertain to the cost center "forest roads", which fairly well equates the cost center "silviculture". The share of forest roads in terms of running expenses (approximated as costs net of depreciation) is 7.1%. A detailed breakdown of the types of costs is shown in Table 1.

The most noticeable type of cost is maintenance and repair (further noted as maintenance), which makes up 59.3% of the enterprises´ sum of this type of cost (sum of type of cost, % Σ TOC). More than 50% of the total costs of forest roads are spent on maintenance (sum of cost center, % Σ CC).

More than one-third of depreciation (38.7%) pertains to forest roads, whereas the shares of investment (31.8%) and net book values (29.4%) are clearly lower. The rate of investment expresses the ratio of investments to depreciation. The mean value for the forest roads and their sub-cost centers in the A-FAN is below 100%. Unlike machinery or computing equipment, roads do not require investments for replacement. Once the opening-up of an enterprise is completed, hardly any further investments will take place, so that the rate of investment may even drop to zero. Similarly, the book values, which are constantly reduced by depreciation, diminish towards pro memoria figures, and ultimately depreciation itself expires. It is worth noting that in terms of managerial accounting, the working life of forest roads could be considered infinite, so that depreciation is zero from the

beginning. Regarding the rules and practice along with the A-FAN, however, depreciation is usually taken in financial accounting as an underlying working life of between 10 and 33 years, and a reference figure of 10 years is suggested. By calculating the ratio of depreciation to net book values, the remaining depreciation period for forest roads can be assessed. The respective average figure is approximately 5.7 years. In those cases where sub-cost centers are addressed, there is a clear dominance of own forest roads, which account for almost 90% of the total cost. Due to the fact that different sub-samples refer to the three sub-cost centers, their average shares on total cost of forest roads do not add up to 100.0% in Table 1. (e.g., the cost of skidding trails accounts for 16.1% of the total if this sub-cost center is addressed at all).

Table 1. Costs recorded for forest roads in total, as well as the corresponding sub-cost centers. Presented as share in terms of sum of type of cost (% Σ TOC) and sum of cost center (%Σ CC). Mean values for the fiscal years 2008–2017.

Type of Cost	Cost Center Forest Roads		Own Forest Roads	Sub-Cost Center Common Property Forest Roads	Skidding Trails
	% Σ TOC	% Σ CC	% Σ CC	% Σ CC	% Σ CC
Gross labor cost	3.2%	9.2%	9.3%	4.0%	11.3%
Energy and Material	12.6%	8.1%	8.6%	4.2%	4.4%
Outside services	9.1%	56.6%	53.5%	85.8%	78.2%
Thereof Maintenance	59.3%	53.6%	51.2%	59.0%	77.9%
Taxes and other cost	0.7%	0.4%	0.5%	0.2%	0.2%
Depreciation	38.7%	25.7%	28.2%	5.8%	6.0%
Investments	31.8%	-	-	-	-
Book values	29.4%	-	-	-	-
Rate of investment	-	95.4%	88.4%	51.6%	53.7%
Share on total cost of forest roads	-	-	87.5%	4.0%	16.1%

3.1. Cost of Ongoing Maintenance, Gross Cost, and Net Cost

To estimate the cost of ongoing maintenance, the sum of costs for the (sub) cost center is reduced by the depreciation, which makes up 25.7% of the forest roads´ total costs. Then, it is possible to divide the cost of ongoing maintenance by the size of commercial forest land (€/ha), actual felling volume (€/m^3 FV), and allowable cut (€/m^3 AC) or length of the forest road network (€/m), as shown in Table 2. Such ratios are valuable for highlighting the significance of individual cost centers, for budgeting exercises, as well as for intertemporal and interfirm comparisons. Conceptionally, the costs of forest roads are considered to be independent from the level of harvesting operations, as is the case with the cost centers "silviculture", "buildings", and "administration". Thus, they underlie fixed cost digression: the higher the felling volume, the lower the resulting figure per m^3 is. In contrast to the volatile annual felling volume, the allowable cut is usually a constant figure, at least for a couple of years. Hence, some comparisons are more significant when referring to the allowable cut instead of the actual felling volume. Table 2 comprises respective results per m^3 of allowable cut in order to exemplify the approach. Quoting and comparing figures per m^3 AC is quite popular in Austria but is not common in other countries. Consequently, the results from Table 3 onwards do not comprise this kind of information. Regardless, by making reference to 10-year averages, the volatility of values per m^3 FV is mitigated and the acreage becomes another solid reference for comparisons.

The average cost for maintenance of forest roads amounts to 0.63 €/m (total cost of the cost center related to the total length of forest roads) and for own forest roads amounts to 0.58 €/m (cost of the sub-cost center related to the length of own forest roads). The coefficient of variation (CV) indicates a wide range for an individual forest enterprise´s cost. The presented values for common property forest roads and skidding trails are indicative only, as they are specifically recorded by only 21% and 7% of the enterprises in the A-FAN. Nevertheless, the figures presented in Table 2, showing an average cost of maintenance of some 0.45 €/m for common property forest roads and just 0.11 €/m for skidding

trails, provide empirical evidence for respective differentiation of cost levels for different categories of the road network.

Table 2. Average annual cost of maintenance given in €/ha, €/m^3 felling volume (FV), €/m^3 allowable cut (AC), and €/m, with the corresponding coefficient of variation (CV). Mean values for the fiscal years 2008–2017.

Cost Center and Sub-Cost Centers	Maintenance							
	€/ha	CV	€/m^3 FV	CV	€/m^3 AC	CV	€/m	CV
Forest roads	27.94	61%	4.07	60%	4.75	81%	0.63	162%
Own forest roads	24.09	70%	3.56	73%	1.66	100%	0.58	163%
Common property forest roads	1.54	167%	0.24	148%	6.41	166%	0.45	267%
Skidding trails	8.64	258%	1.10	280%	0.91	277%	0.11	2469%

Table 3. Average annual cost of maintenance, depreciation, total cost, total revenue, net cost of investments, and book values of forest roads. Mean values of the fiscal years 2008–2017 expressed in €/ha, €/m^3 FV, and €/m.

Forest roads	€/ha	€/m^3 FV	€/m
Maintenance	27.94	4.07	0.63
Depreciation	9.79	1.43	0.22
Total cost	37.73	5.50	0.86
Total revenue	5.35	0.78	0.12
Thereof Subsidies	2.28	0.33	0.05
Net cost	32.39	4.72	0.73
Investments	9.35	1.36	0.21
Book values	56.16	8.19	1.28

The total costs of forest roads, including the depreciation, are 0.86 €/m, as presented in Table 3. By discounting specific revenues, such as road usage charges, reimbursements, and subsidies, the net costs are calculated at 0.73 €/m. On average, 14.2% of the costs are compensated by revenue, with 42.7% consisting of road usage charges, 14.6% reimbursements, and 42.7% subsidies, which is attributed to the specific cost center. The sum of maintenance and current investment net of revenues indicates the cash requirements and amounts to some 31.9 €/ha. Subsidies are mostly related to investments and contribute 24.4% to financing these.

The results presented so far are based on the reported values of all participating enterprises in the A-FAN for the fiscal years 2008–2017. Around 10% of the evaluated enterprises provide additional information on the length of yearly road maintenance, which corresponds directly with the recorded cost. Based on these values, it is possible to perform unit costing. On average, 9% of the forest road network is maintained annually, which leads to an approximately decennial maintenance circle. The average value for maintenance is 5.9 €/m, including the cost for snow clearance. Deducting the cost for this activity, which is 0.3 €/m (1.5 €/ha), leads to a pure maintenance cost of 5.6 €/m. It has to be noted, however, that these are just indicative figures derived from a small sub-sample of the FAN, so they must not be interpreted as representative for all bigger forest enterprises in Austria.

3.2. Significance in Terms of Contribution Margin and Corresponding Cutting Volume

The conceptual framework of the A-FAN comprises a stepwise calculation of contribution margins. In each step of the calculation, a cost center's net cost is subtracted, starting with the timber revenues, as shown in Table 4. The net costs of each cost center are derived by subtracting specifically allocated revenue from the gross figures. The net costs of forest roads are considered in step 2, leading to contribution margin II (CM II). To cover the cost of the forest roads, which is 4.72 €/m^3, roughly 10% of CM I is needed. Further analysis refers to the corresponding cutting volume (CCV). In this concept, the net costs of a cost center are transformed into the equivalent volume of timber valued at the

average CM I per m^3. In a further step, this volume is related to the felling volume, as well as to the allowable cut. In addition to the monetary figures, these ratios show the magnitude (with the share of the actual harvest on the one hand and the allowable cut on the other), which is required for financing a specific cost center. On average, 10.4% of the FV (12.1% of the AC) is needed to cover the net costs of forest roads.

Table 4. Calculation of profit or loss using the concept of stepwise contribution margin (CM) calculation. Mean values for the fiscal years 2008–2017 given in €/ha and €/m^3 FV. The corresponding cutting volume (CCV) expresses the m^3/ha, as well as the share of the felling volume (FV) or allowable cut (AC) required to cover a cost center's net costs.

CM Steps	€/ha	€/m^3 FV	CCV in m^3/ha	CCV in % FV	CCV in % AC
Timber revenues	484.70	70.65	-	-	-
−Timber harvesting	−174.01	−25.36	-	-	-
CM I	310.69	45.28	-	-	-
−Forest roads	−32.39	−4.72	0.72	10.4%	12.1%
CM II	278.31	40.56	-	-	-
−Silviculture	−30.41	−4.43	0.67	9.8%	11.4%
CM III	247.90	36.13	-	-	-
−Buildings	−15.37	−2.24	0.34	4.9%	5.8%
CM IV	232.53	33.89	-	-	-
−Administration	−105.77	−15.42	2.34	34.0%	39.7%
Profit (+) or Loss (−)	126.75	18.47	-	-	-

3.3. Analysis of Differences between Sub-samples

Five different variables ("size class", "production conditions", "coherence of estate", "average slope", and "share of forest land requiring cable yarding") were used to group the A-FAN's enterprises and then assigned to different classes. The classes of the variables "size class", "coherence of estate", and "share of forest land requiring cable yarding" stem directly from the A-FAN [38]. Additional classes were introduced twice by combining two existing classes. The size classes "1201–5000 ha" and ">5000 ha" were merged into a new class ">1200 ha", while the classes "mediocre" and "bad" were assigned to one class, "mediocre or bad". The variable "production conditions" uses a reclassification of the six forest production areas in Austria, which on a purely geographical basis roughly characterize the natural production conditions. Enterprises located in the central alps, limestone alps, and eastern alps were assigned to the class "mountainous", whereas the alpine foothill regions, the Wald and Mühlviertel, as well as the eastern plains, were classified as "non-mountainous". A mountainous setting is generally associated with higher altitude and steeper terrain, and indirectly related to harvesting conditions, tree species composition, as well as the range of silvicultural systems. Regardless, site conditions and productivity may vary considerably in both of these analytically interesting aggregates [46]. The variable "average slope" groups enterprises by the maximum average slope of 35%, which is recommended as the slope limit for rubber-tired skidders and forwarders [47]. As the average slope is a non-obligatory attribute in the A-FAN, it is reported only by half of the enterprises (*n* = 64). The results are visualized in terms of boxplots in Figure 1. The different colors refer to the 5 variables, with each boxplot representing a single class.
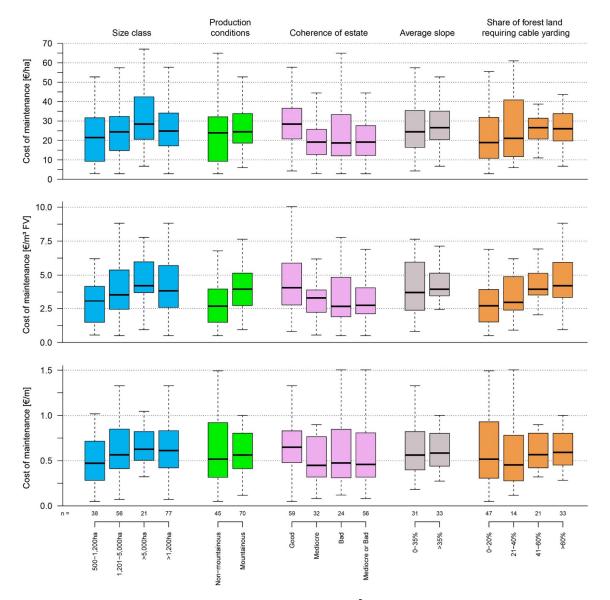
Figure 1. Range of the annual cost of maintenance in €/ha, €/m³ felling volume (FV), and €/m forest road in the Austrian Forest Accountancy Data Network, shown as boxplots. The enterprises are assigned to classes according to 5 different variables ("size class", "production conditions", "coherence of estate", "average slope", "share of forest land requiring cable yarding"). Outliers are not shown.

To test the null hypothesis that the classes for each grouping variable stem from identical populations, Kruskal–Wallis tests were performed. According to the results presented in Table 5, the null hypothesis is rejected in several cases. The median maintenance cost for forest roads of enterprises with a productive forest area of 500–1200 ha (3.08 €/m³ FV or 0.47 €/m) is significantly lower than from enterprises with > 1200 ha (3.84 €/m³ FV or 0.61 €/m). Furthermore, the maintenance costs per m³ FV in larger holdings are significantly higher, whereas the road density (m/ha) and felling intensity (m³/ha) show no difference. Maintenance cost per m³ FV is significantly lower under non-mountainous production conditions (2.68 €/m³ FV) than under mountainous ones (3.97 €/m³ FV). This specific difference is explained by significantly lower road densities and higher felling intensity in non-mountainous regions. When grouping the enterprises according to their coherence of estate, the groups show significant differences in road maintenance cost per ha forest land, per m³ FV, and per m forest road. Enterprises with a good coherence of estate show higher costs than ones classified as mediocre or bad, whereas no significant differences exist between road densities or felling intensities. For the better half of the enterprises, the average slope of the forest land is documented.

The groups based upon the average slope show no significant differences in any of the tested key figures. Enterprises with higher shares of forest land requiring cable yarding show significantly higher maintenance costs for forest roads per m³ FV. These differences can partially be explained by significant differences of felling intensities and road densities.

Table 5. Class sizes (n); median value of annual maintenance cost of forest roads per ha, per m³ felling volume (FV), and per m forest road; as well as the road density in m/ha and the felling intensity in m³/ha. Furthermore, the *p*-values and significance values of the classes according to the groupings of enterprises by 5 different variables are presented; * significance level < 0.05, ** significance level < 0.01.

Grouping by	Class	n	Median and *p*-Values				
			€/ha	€/m³ FV	€/m	m/ha	m³/ha
Size Class	500–1200 ha	38	21.5	3.08	0.47	42.2	7.07
	1201–5000 ha	56	24.4	3.55	0.56	38.9	6.80
	>5000 ha	21	28.4	4.22	0.63	46.2	6.88
	p-value	*115*	*0.1110*	*0.0152 **	*0.0581*	*0.1931*	*0.7735*
	500–1200 ha	38	21.5	3.08	0.47	42.2	7.07
	>1200 ha	77	24.8	3.84	0.61	40.9	6.80
	p-value	*115*	*0.1097*	*0.0309 **	*0.0231 **	*0.6237*	*0.8212*
Production conditions	Non-mountainous	45	23.9	2.68	0.52	36.2	7.79
	Mountainous	70	24.4	3.97	0.56	48.6	6.53
	p-value	*115*	*0.1347*	*0.0021 ***	*0.9589*	*0.0027 ***	*0.0191 **
Coherence of estate	Good	59	28.4	4.07	0.65	48.8	6.90
	Mediocre	32	19.1	3.32	0.45	37.9	6.47
	Bad	24	18.7	2.66	0.47	34.2	7.84
	p-value	*115*	*0.0056 ***	*0.0061 ***	*0.0376 **	*0.2572*	*0.2219*
	Good	59	28.4	4.07	0.65	43.8	6.90
	Mediocre or Bad	56	19.4	2.74	0.46	37.5	6.72
	p-value	*115*	*0.0014 ***	*0.0014 ***	*0.0105 **	*0.0994*	*0.6912*
Average slope	≤35%	31	24.5	3.72	0.56	40.4	6.70
	>35%	33	26.6	3.96	0.58	50.0	6.84
	p-value	*64*	*0.3717*	*0.3936*	*0.8772*	*0.0522*	*0.7522*
Share of forest land requiring cable yarding	≤20%	47	18.9	2.70	0.52	37.7	7.36
	21–40%	14	21.1	2.95	0.45	48.5	7.80
	41–60%	21	26.6	3.96	0.57	54.3	6.36
	>60%	33	26.0	4.22	0.59	43.7	6.35
	p-value	*115*	*0.2413*	*0.0050 ***	*0.5425*	*0.0372 **	*0.0409 **

Furthermore, the following three hypotheses were tested:

(i) The share of damaged timber and the ratio felling volume to allowable cut (utilization ratio) show significant differences between various groups, and are correlated with felling intensity and maintenance costs of forest roads per ha, per m³ FV, and per m forest road.

Enterprises in the class with an average slope above 35% have a significantly higher share of damaged timber (36.7%) and utilization ratio (1.18) than enterprises with a lower average slope (23.5% and 1.08, respectively). The further groupings indicated no significant differences for these variables. The utilization ratio is a statistically significant weak positive correlated with the felling intensity ($r = 0.325$). All other tested correlations showed no significance.

(ii) Harvesting costs show significant differences between various groupings and are correlated with the maintenance costs of forest roads per ha, per m³, and per m forest road.

The total costs for felling, bucking, and hauling to the roadside (without possible reimbursement and subsidies) referring to the forest land and to the corresponding felling volume were tested for

significant differences between the classes of the different groupings (see Table 6). Whereas the size class and the coherence of estate do not seem to influence the harvesting cost, statistically significant differences could be found in the other groupings. The harvesting costs per m^3 FV are significant lower under non-mountainous production conditions if the average slope of the forest land is in the lower 35% and if the share of forest land requiring cable yarding is low. In addition, significant differences of harvesting costs per ha forest land exist between enterprises with average slopes below or above 35%. Harvesting costs per ha ($r = 0.383$) and per m^3 FV ($r = 0.191$) are significant but weakly positively correlated with the maintenance costs of forest roads per ha. This also applies to the correlation of harvesting cost per m^3 FV and maintenance cost per m^3 FV ($r = 0.312$).

Table 6. Class sizes (n) and median value of harvesting costs per ha and per m^3 felling volume. Furthermore, the *p*-values and significance values of the classes according to the groupings of enterprises by 5 different variables are presented; ** significance level < 0.01, *** significance level < 0.001.

Grouping by	Class	n	Median and *p*-Values €/ha	€/m^3 FV
Production conditions	Non-mountainous	45	151.1	22.3
	Mountainous	70	176.8	28.6
	p-Value	*115*	*0.0738*	*<0.0001 ***
Average slope	≤35%	31	149.5	25.4
	>35%	33	187.6	28.7
	p-Value	*64*	*0.0093 **	*0.0005 ***
Share of forest land requiring cable yarding	≤20%	47	150.6	22.4
	21–40%	14	182.6	25.4
	41–60%	21	177.6	28.2
	>60%	33	176.0	30.8
	p-Value	*115*	*0.0924*	*<0.0001 ***

(iii)   The profit from timber production differs significantly between various groupings and is correlated with felling intensity and maintenance cost of forest roads per ha, per m^3 FV and per m.

The profit from timber production per ha is statistically different for two of the tested groupings. Enterprises with non-mountainous production conditions have significantly higher profits (145.0 €/ha) than enterprises with mountainous conditions (105.8 €/ha). Furthermore, the share of forest land requiring cable yarding negatively influences the profit from timber production. The profit per ha of enterprises in a respective class decreases constantly in the classes ≤20% (145.0 €/ha), 21–40% (136.1 €/ha), 41–60% (122.4 €/ha), >60% (80.6 €/ha). While the profit from timber production is significantly correlated with the felling intensity ($r = 0.700$), it is not significantly correlated with the maintenance costs of forest roads per ha, per m^3 FV, or per m. This is not surprising at interfirm level, as there are multiple factors responsible for the operational result. Regardless, this does not necessarily mean that the maintenance costs are negligible for some enterprises. Further determination based on the available dataset is not possible, as it comprises a documentation of the input in terms of cost, but no further information is given about the output in terms of the road condition.

4. Discussion and Conclusions

The empirical results presented in this paper are indicative and by no means claim representativeness, with Austria being a small country and the dataset being limited. However, they are considered valuable as they provide some insights into a scarcely researched topic, as well as a reference for comparative analyses. On average, larger Austrian forest enterprises assign 9.0% of their total cost to the cost center "forest roads". Reference values are 5.0% for the Bavarian State Forestry (BSF) [48], 7.0% for public and 5.9% for private German enterprises, and 10.0% for Swiss forest

enterprises (results for the fiscal years 2008–2012 [49]). More than half of the gross cost of this cost center pertains to maintenance. More than one-third of the enterprise's depreciation stems from forest roads, making up a quarter of the forest road costs. In contrast to other capital goods, there is no direct need for reinvestment in forest roads. Thus, the average rate of investment is permanently below 100%, which may well indicate progress towards reaching the intended forest road density, which is quite common in Central Europe [50,51].

To cover the ongoing maintenance costs of forest roads in the A-FAN, 10.4% of the felling volume or 12.1% of the allowable cut are required. Relating cost to the total length of the road network results in an annual average value of 0.63 €/m in the A-FAN. This value fits with the ranges reported for the German State Forest of Baden-Württemberg (BWSF) (0.43 €/m [50]), the BSF (0.60 €/m [48]), and the Austrian federal forests (0.50–1.00 €/m [52]). The sum of the cost for ongoing maintenance and the net investment cost is 31.9 €/ha and can be used as a surrogate in liquidity planning. Unit values, where the costs of maintenance are related to the length they are actually maintained, are documented for only a few cases, with an average of 5.6 €/m. The respective data indicates that the road network requires maintenance roughly every ten years. Depending on the type of maintenance, individual costs per m may vary to a great extent. On average, forest enterprises of the A-FAN invest 9.4 €/ha in forest roads per year, which is subsidized by approximately 24.4%. In comparison, the subsidies for forest roads in the period 1968–1996 for smaller forest holdings ranged between 31.2% and 46.0%, as documented by the forestry report [5–7].

Calculating the enterprise profits stepwise allows the identification of different contribution margins. By using this concept, it is possible to identify the cost for each step of production, which can consequently be referred to a reference figure. The net cost of forest roads per m^3 felling volume in the A-FAN is 4.72 €/m^3, as shown in Tables 3 and 4, with the average cost of maintenance itself being 4.07 €/m3. These values fit in the range of values for road maintenance reported for the Federal State of Bavaria (3.50–5.50 €/m^3 [51]), BWSF (2.35 €/m^3 [50]), and the FAN values for Germany (3.61 €/m^3) and Switzerland (7.34 €/m^3) (results for the fiscal years 2008–2012 [49]). For the calculation and interpretation of the presented results, some special characteristics of FANs and the recorded maintenance cost have to be kept in mind. Where possible, it seems appropriate to use longer time spans (e.g., 10 fiscal years) for the evaluation, which is in-line with the general concept of a FAN [35]. As a result, two problems can be solved: (i) intermittent maintenance work; and (ii) the time lag between extraordinary harvesting volumes, for example triggered by disasters (e.g., wind throw) and necessary maintenance work.

To test whether statistically significant differences exist in the maintenance costs between enterprises, they were classified according to 5 different grouping variables, namely "size class", "production conditions", "coherence of estate", "average slope", and "share of forest land requiring cable yarding". Depending on the reference figure (ha, m^3 FV, or m forest road), the maintenance costs of forest roads show significant differences between the classes within the respective groups. The results indicate that forest enterprises with a forest area of 500–1200 ha have statistically significant lower maintenance costs per m^3 FV and per meter forest road, as well as lower harvesting costs per m^3 FV than those with >1200 ha, whereas there is no difference in the felling intensity and the forest road density. The class sizes are historical values used in the A-FAN [38] and are not necessarily optimal splitting points, such as those determined with statistical approaches. The second grouping applied to the dataset were the "production conditions", classifying enterprises under mountainous or non-mountainous conditions according to their dominant location in one of the six forestry production areas. The results show statistically significant lower maintenance costs for forest roads (€/m^3 FV) and harvesting cost (€/ha and €/m^3 FV) and higher profits for timber production (€/ha) under non-mountainous production conditions. These differences are mostly caused by significantly lower road densities and higher felling intensity in enterprises with non-mountainous production conditions. The "coherence of estate" is the third variable for classes with statistically significant different maintenance costs per ha, per m^3 FV, and per m forest road. The classes are assessed by

the enterprises themselves and express the spatial distribution of the enterprise's districts [38]. It is notable that enterprises with worse spatial distribution seem to have lower maintenance costs than the other group members, whereas no further statistically significant differences between the classes could be found in the investigated variables. Using the average slope of forest land, enterprises were split into two groups, below and above 35%, which is the slope limit for rubber-tired skidders and forwarders [47,53]. Whereas no significant difference exists between maintenance costs for forest roads, road density, and felling intensity, enterprises in the group above 35% have significant higher utilization ratios and harvesting costs (€/ha and €/m^3). The latter is explained by the higher harvesting cost per m^3 for cable yarding compared to ground-based harvesting technologies. A-FAN enterprises extracting the better part of timber through cable-based techniques show a significantly higher harvesting cost of 35.3 €/m^3 FV than those using mainly ground-based extraction, t 28.1 €/m^3 FV (average fiscal years 2008–2017). These results fit very well in the range of harvesting costs used for preliminary costing [54]. The fifth grouping variable divides the enterprises into four groups according to their share of forest land requiring cable yarding, which is an attribute used in the A-FAN [38]. Classes with higher shares have significantly higher maintenance cost for forest roads and harvesting cost per m^3 FV, as well as a lower profit for timber production (€/ha). Although the maintenance cost for forest roads shows significant differences between various groups of enterprises, the results themselves have no explanatory power, as no measures for the effectiveness and efficiency of the measures are provided. The testing of the variables "share of damaged timber", "utilization ratio", "harvesting cost" (€/m^3 FV and €/ha), and "profit from timber production" (€/ha) showed several significant differences between the groupings. Strong correlations between those variables and the maintenance costs (€/ha, €/m^3 FV, and €/m forest road) could not be found. This finding corresponds to the findings of Becker [50] for the State Forests of Baden-Württemberg. Farsi et al. [55] showed that Swiss forest enterprises with higher road density had lower harvesting costs. For the enterprises in the A-FAN, the correlation between harvesting cost and road density is not statistically significant. Regardless, it is important to consider that the key figure, road density (calculated as meters forest road per ha forest land), is a very common but not necessarily valid indicator for describing the access situation [8,12,15].

Especially in areas with a long tradition of forestry, such as in Central Europe, the initial opening-up of forests goes back several decades. Typically, basic road networks were upgraded and expanded stepwise in order to fulfill the current requirements for transportation, such as the switch from horses and floating vehicles to skidders and trucks. Thus, forest road networks often show potential for optimization in terms of dismantling and upgrading existing forest roads. Combined with the optimization of routing, maintenance costs of forest roads can be reduced by 20–25% [50]. Furthermore, maintenance costs can be reduced by using sophisticated approaches, such as the analytic hierarchy process [56]. Including information about the terrain surface properties and geological properties of the subsoil in the planning process can help reduce road life-cycle costs significantly [21,57]. According to Heinimann [53], the engineering of forest roads evolved from a technical task of cost minimization to a process involving public and environmental issues during the 1980s. The economic appraisal of an investment in a forest road is a complex process that should consider all costs and benefits, whether economic, social, environmental, or financial [58]. Costs and benefits in this context may comprise effects that can hardly be expressed in monetary values, such as strain damages along the forest boundary, influences on the ground water balance and sediment dispersion to streams [19], reduction of productive forest land [59], influences of the annual increment, increasing risk for windthrows along forest roads, provision of food for wildlife, better accessibility for recreation seekers and rescue services [24,30], obligation to ensure road safety, problems of acceptance by local communities [60], influences on biodiversity [13,26], and risk of forest disease [61]. This complexity may lead to prohibitively high transaction costs caused by stakeholder discussion, contact with authorities, required expert reports, and other factors.

The future of the further opening-up of forests and forest road maintenance costs is definitely challenging. Especially in countries such as Austria, where the forests are generally accessible to

the public, requests on behalf of various stakeholder groups will continue to increase. The general development of the bioeconomy [62,63] implies a more comprehensive utilization of forest resources. Technically demanding projects are required, especially in mountainous regions, in order to expand the economically recoverable inventory in a sustainable way [15,29]. More frequent heavy rain events and shorter or missing periods of frozen soil, as brought about by climate change, are most likely to trigger a significant increase in maintenance costs. Further inter- as well as transdisciplinary research is needed in order to effectively support individual forest enterprises, associations, and communities in optimizing their road networks and in minimizing respective maintenance costs [25]. A current example of such research efforts is the EU-funded project TECH4EFFECT [64], in which one of the research questions relates to the effects of humidity on roadways in terms of the trafficability of forest roads.

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