AN ESTIMATION OF THE ROTATION AGE USING AUTOREGRESSIVE PRICE MODEL AND TRUNK ANALYSIS DATA: RESULTS FOR *PINUS BRUTIA* TEN

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Abstract. The present study was conducted in southwestern Iran and it aimed to determine the optimal rotation age of Turkish pine (*Pinus brutia* Ten) at which the marginal revenue equaled to the marginal cost. The volume growth, stumpage price, setup cost and interest rate were considered as essential factors for calculating the optimal rotation age. The data of volume growth were extracted through Trunk Analysis Method and stumpage price of *Pinus brutia* was estimated through autoregressive model. The results showed that the optimal harvest age of *Pinus brutia* occured in the age range of 18 to 23 years when the land's expected value maximizes. It is noteworthy that cultivation of the stated species was found to be economically justifiable in this area.
Keywods: *Pinus brutia, Turkish pine, stumpage price, optimal rotation age, Faustmann model*

Introduction

Forest rotation refers to the period of time between stand establishment and harvest which is applied for forests with even-aged management. On the other hand, rotation age refers to the age when stand must be harvested or clear-cut. The calculation of this period is necessary to achieve the economic and sustainability goals of the harvester (Posavec et al., 2011). The most commonly used criteria to maximize productivity of forest stands are: (1) maximum single-rotation physical yield (2) maximum single-rotation annual yield (3) maximum internal rate of return (4) maximum annual net revenues (5) maximum discounted net revenues from an infinite series of rotation (Newman, 1988). The idea of optimal economic age was first introduced by Faustmann (1849) and is extensively used in evaluating the financial maturity of a forest stand. Regarding this criterion, foresters and natural resources managers have traditionally assumed that forestlands will be under timber production for ever, under the condition that the harvested stands are rapidly replaced by other ones. Therefore, Faustmann criterion is called discounted benefits to infinity (DBI) or land's expected value (LEV). In this model, optimal solution occurs when the land's expected value is in its maximum level and marginal revenue of production equals marginal cost of input (Chang, 1984).

Since 1957 optimal rotation age has been studied by various researchers using the models with different levels of complexity (Gaffney, 1957; Näslund, 1969; Anderson, 1976; Reed, 1986; Engindeniz, 2003; Petit and Montagnini, 2004; Posavec et al., 2011; Pourmajidian et al., 2013; Brazee and Dwivedi, 2015). Some of these studies have used Faustmann criterion (Zhang, 2001; Brazee and Dwivedi, 2015) and other studies have applied other criteria for calculating the optimal rotation age (Engindeniz, 2003; Petit

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and Montagnini, 2004). Chang (1984) investigated the relationship among the Land's Expected Value model, Net Present Value model, Forest Renting model and Traditional Biologic model and showed that the three latter models are special cases of the Land's Expected Value model. Land's Expected Value model is the most accurate model for calculating the optimal rotation age by taking into accounts the opportunity cost of stand as well as opportunity cost of land (Newman, 1988; Pearse, 1967). To determine the optimal economical rotation in even-aged forests, a combination of information including forest growth, stumpage price, cost and interest rate is required (Mohammadi Limaei et al., 2013) and it is usually assumed that: 1) The forest growth and stumpage price are constant. 2) Utilization costs are not undertaken by the owner and trees are sold as stand stock. 3) The risk of pests and tree uprooting is very low and it is ignored. 4) Tax is not paid to government. 5) Thinning is not performed (Amacher et al., 2009).

Since Iran is not rich in terms of native coniferous species, the government has to import paper pulp and long-fibers of coniferous species for the pulp and paper industries demand. These imports remarkably increase the currency outflow. Hence, it must be attempted to develop plantations of fast-growing species or wood farming in various parts of the country (Nouri, 1999; Arian et al., 2017). In the present study, *Pinus brutia* was selected because of its good physical and mechanical properties in commercial pulp production (Üner et al., 2011; Fakhryan Roghani, 2015). The aim of this research is to determine whether this species is economically justifiable or not, and to calculate the maximum net present value in an infinite series or estimate the optimal rotation age.

Materials and Methods

This study was carried out in a 33-year old area under *Pinus brutia* plantation in western Iran. The study area is located at 48º 20' E and 33º 30' N and 1270 m above sea level. The area is characterized by Mediterranean climate with mean annual temperature and mean annual rainfall of 17º C and 552 mm respectively. This plantation was established in 1978 with a planting distance of 2×3 m and is managed by Khorramabad Park and Green Space Organization. As mentioned above, growth value, stumpage price, interest rate and setup costs are essential factors to calculate the optimal age by Faustmann model (Mohammadi Limaei et al., 2013). These parameters are calculated as follows:

Growth of Pinus brutia

Stand measurement method and trunk analysis method are two prevailing approaches to measure the growth characteristics of a tree. In the second method, which is more accurate to estimate growth parameters, trees are cut down and growth component is calculated according to trunk analysis and annual rings count (Zobeiry, 1994).

In this study, the data of growth was extracted from a previous study conducted by Ostakh (2013) to evaluate the effect of climatic factors on the growth rings of *Pinus brutia*. They selected 31 trees using selective method and cut them down. Then five disks were prepared from various heights of trunk. After preparation of disks, the width of annual rings was measured with an accuracy of 0.001 mm for various years. Finally they have estimated the growth components including current annual increment (CAI), mean increment (MI) and volume stock in different ages of considered stand which will be used in the present study (*Table 1*). *Figs. 1.a* and *1.b* show the amount of volume stock (m^3/ha) in various ages and the relationship between CAI and volume stock (m^3/ha).

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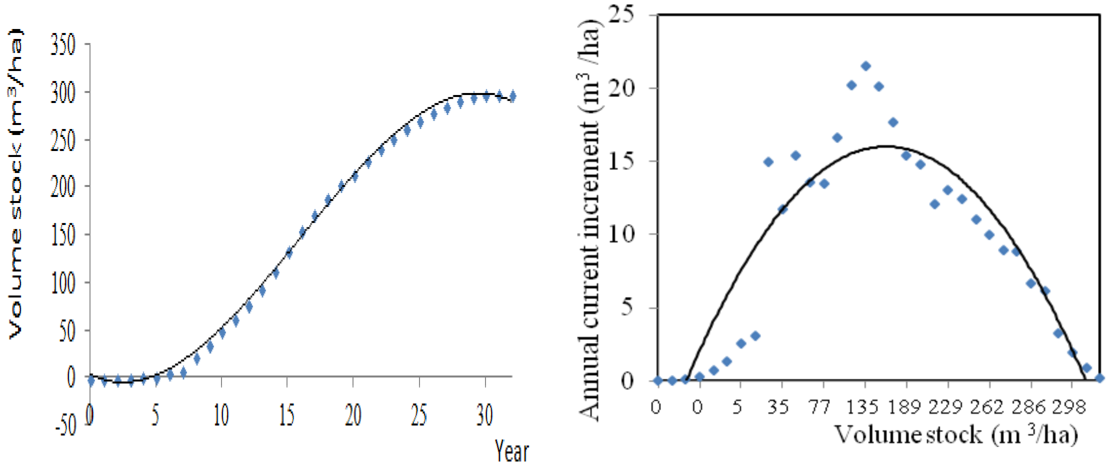

(a) (b)

Figure 1. *a: Volume stock per ha in various ages of the Pinus brutia stand, b: Relationship between CAI and volume stock per ha of the Pinus brutia stand*

Table 1. *Annual increment, mean increment, volume*

Age	Current Annual Increment (m^3/ha)	Mean Increment (m^3/ha)	Volume (m^3/ha)
1	0.0119	0.0119	0.0119
2	0.0357	0.0238	0.0477
3	0.0903	0.0460	0.1380
4	0.2544	0.0981	0.3925
5	0.7468	0.2278	1.1394
6	1.3592	0.4164	2.4986
7	2.5155	0.7163	5.0141
8	3.0516	1.0067	8.0537
9	14.922	2.5542	22.987
10	11.750	3.4737	34.737
11	15.355	4.5539	50.093
12	13.557	5.3042	63.651
13	13.508	5.9353	77.159
14	16.586	6.6961	93.746
15	20.214	7.5972	113.95
16	21.531	8.4681	135.49
17	20.066	9.1504	155.55
18	17.658	9.6230	173.21
19	15.435	9.9289	188.65
20	14.813	10.173	203.46
21	12.088	10.264	215.55
22	12.996	10.388	228.54
23	12.396	10.475	240.94
24	11.068	10.500	252.01
25	9.9699	10.479	261.94
26	8.9584	10.420	270.94
27	8.8442	10.362	279.78
28	6.7028	10.231	286.48
29	6.0968	10.089	292.58
30	3.2545	9.8613	295.84
31	1.9349	9.6056	297.77
32	0.8587	9.3323	298.63
33	0.1744	9.0548	298.80

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Estimation of the stumpage price equation of Pinus brutia

There are two approaches to estimate the wood price among economists. According to the first approach, the price follows a stationary autoregressive model, that is to say, the changes which occur in a period will have no significant effect on the price of the next period and the best method for forecasting the price is to calculate the average of the previous prices. This way, prices can be estimated using the following formula: $P_{t+1} = \alpha + \beta P_t$, where $0 < \beta < 1$.

In the second approach, the price is non-stationary and does not follow the aforesaid stationary condition. In this situation, the price in the next year or period completely depends on the price in previous year or period. The price in this case, can be evaluated as $P_{t+1} = \beta P_t$, β=1 (Lindahl and Plantinga, 1997; Dickey and Fuller, 1981; Mohammadi Limaei, 2006).

After testing the price data, it was found that due to the stationary type of data, stationary autoregressive model was used for estimating the parameters. It should be noted that the data of the period 1993-2012 was collected from the Natural Resources Organization and interview carpenters. Then it was adjusted to Consumer Price Index (CPI) of Iran for the base year of 2011 (*Fig. 2*) (Central Bank of Iran, 2014).

$$P_r = \frac{P_t}{y_t} \times 100 \quad \text{(Eq.1)}$$

Where Pr is the real price, Pt is the price in year t and yt is the price index in year t and 100 is the value of price index in basic year (Branson, 1989).

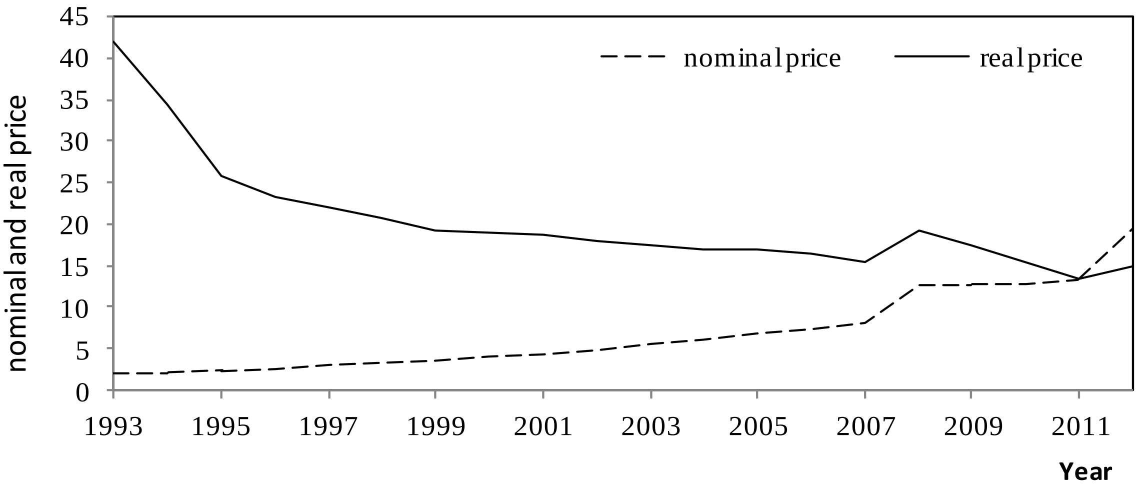

Figure 2. *Nominal (non-adjusted) and real (adjusted) prices of Pinus brutia in period of 1993-2012*

Then, a regression model was used for estimating the price of each m^3 of the *Pinus brutia Ten* (Lindahl and Plantinga, 1997; Mohammadi limaei and Lohmander, 2007).

$$p_{t+1} = \alpha + \beta p_t + \varepsilon_t \quad \text{(Eq.2)}$$

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Here, it is assumed that ε_t is a sequence of errors with normal distribution, mean of zero and zero autocorrelation. P_{t+1} is the price in the year t+1 and P_t is the price in year t. Expected mean stumpage price is calculated as follows:

$$P_{eq} = \frac{\alpha}{1-\beta} \quad \text{(Eq.3)}$$

Faustmann expected value

Since Faustmann formula includes economic parameters in estimation of rotation age, it was chosen to be applied in this study. In this method it is attempted to select the length of rotation so that the land's expected value is maximized.

Details of Faustmann model, which assumes that a land will be under forest cultivation forever, is explained as follows: net present value resulting from harvesting after the first rotation is shown in Eq. 4, where T is the decision variable or rotation period, p is the price per m^3 of stumpage, f (T) is the standing volume stock in time T, r is the interest rate, c is set up cost in time 0, and e is Nepper number. Here, e^{-rT} is referred to as discount rate which is continuous time approximation of $\frac{1}{(1+r)^T}$.

$$pf(T)e^{-rT} - c \quad \text{(Eq.4)}$$

Net present value of an infinite series with similar rotations is stated as follows:

$$pf(T)e^{-rT} - c + [pf(T)e^{-rT} - c]e^{-rT} + [pf(T)e^{-rT} - c]e^{-2rT} + [pf(T)e^{-rT} - c]e^{-3rT} + \dots \quad \text{(Eq.5)}$$

By factoring $(pf(T)e^{-rT} - c)$, an infinite converging series can be obtained:

$$(1 + e^{-rT} + e^{-2rT} + e^{-3rT} + \cdots)(pf(T)e^{-rT} - c) \quad \text{(Eq.6)}$$

By summing the converging function to infinite which is obtained by multiplying the first term by $\frac{1}{1-q}$ (q is common ratio of progression as e^{-nr}) and by substituting the sum of converging function in the series shown in number 6:

$$v = pf(T)e^{-rT} - c(1 - e^{-rt})^{-1} \quad \text{(Eq.7)}$$

Here, numerator of the fraction shows the present value of a rotation and denominator indicates the discount factor of future rotations to infinite. This equation is called Faustmann equation, land's expected value (LEV), or soil's expected value (SEV). To obtain the age at which net present value of forest is maximized, the derivation of the above term is set equal to zero.

$$v_T = pf'(T) - rpf(T) - rv = 0 \quad \text{(Eq.8)}$$

And finally, optimality condition of the Faustmann model is as follows:

$$pf'(T) = rpf(T) + rv \quad \text{(Eq.9)}$$

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According to the optimality condition of the Faustmann model, age is increased to a point that marginal revenue equals marginal cost. Here, f'(T) is the current increment of the year T.

Results

Growth of Pinus brutia

According to *Table 1*, maximum annual current increment of the species is 21.531 m^3 per ha and volume stock in age 33 is 298.80 m^3 per ha. Current Annual Increment (CAI) and Mean Annual Increment (MAI) will be equal at the age of 24 which is called biologically optimal rotation age.

Stumpage price model for Pinus brutia

As explained in *Fig. 2*, the change in trend of nominal price is in line with real price, however, real price increases with a higher slope in comparison to nominal price. It means that a major portion of increase in the price of *Pinus brutia* in the study period has occured as a result of inflation. Assessing the details of the nature and reasons of inflation in various years which may be due to increase in demand, structural inflation, inflation expectations and inflation as a result of expenses pressure is out of the limits of this work.

After adjusting the data for the base year (*Fig. 2*) autoregressive analysis was used to estimate the expected prices. According to the results and the t-value with a confidence level of 95%, it was found that there was a significant correlation between parameters P_{t+1} and P_t. Moreover, the results of this analysis revealed that β varied between 0 and 1, and stationary condition was observed (*Table 2*).

Table 2. *estimated parameters using autoregressive analysis*

	α	β	R	R^2	**Standard deviation of ε**
Parameter value	186379.95	0.655	0.957	0.916	46598.47804
Standard deviation	34132.095	0.048			
T-statistics	5.461	13.644			

Price predicting equation for *Pinus brutia* was calculated through the estimated parameters obtained from the regression analysis, and substituting the value of parameters α and β in Eq. 2, as follows:

$$P_{t+1}=186379.95+0.655P_t \quad \text{(Eq.10)}$$

And using Eq. 3, expected mean stumpage price of *Pinus brutia* was obtained to be 540229 RLs (16$) per 1 m^3.

$$P_{eq} = \frac{186379.95}{1-0.655} = 540229 \quad \text{(Eq.11)}$$

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Economic rotation age of Pinus brutia

As mentioned above, four main components are needed for calculating the LEV. The Growth data was extracted from the trunk analysis table provided by Ostakh (2013), and the expected price mean was predicted by autoregressive model. Interest rate and set up cost were considered 2%-8% and 500000-1000000 RLS (15.26 – 30.52 $), respectively. After substituting the mentioned components in Faustmann formula, optimal rotation age was calculated, where land's expected value was maximized or marginal revenue of production equaled marginal cost of input. As seen in *Table 3* optimal rotation age fluctuates from 18 to 23 years owing to different interest rates and various setup costs. It can be said by increasing interest rate, optimal rotation age will decrease and by reducing the setup cost, optimal rotation age will increase.

Table 3. *The Optimal rotation age considering various interest rates and setup costs*

Interest rate setup cost	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**
500000	22	20	20	19	19	18	18
600000	22	20	20	19	19	18	18
700000	23	20	20	20	19	18	18
800000	23	20	20	20	19	18	18
900000	23	20	20	20	19	18	18
100000	23	22	20	20	19	18	18

Discussion and Conclusion

One of the most important goals of planting the coniferous species in Iran is rehabilitation and restoration of degraded forests as pioneer species during succession stages (Sardabi, 1998). Although most of *Pinus brutia* plantations are planted for aesthetic and protective purposes, research has revealed that they are suitable in terms of growth efficiency for wood production (Fattahi, 1994; Radaei, 2002).

As mentioned above, in this study, the growth data were extracted from the trunk analysis table which was calculated by Ostakh (2013), Since the trunk analysis method has higher accuracy in estimating the stand volume in comparison to stand measurement method (Zobeiry, 1994), in the present study, the required growth data for calculating the optimal rotation age was extracted through trunk analysis method for the first time. While in most of the previous studies focusing on the rotation age, stand measurement method was used for gathering the growth data (Mohamadi Limaie et al., 2013; Ranjbar et al., 2009).

As shown in *Table 2*, studied plantation with CAI, MAI and stock volume equal 20.066 (m^3/ha), 9.1504 (m^3/ha) and 155.55 (m^3/ha), respectively at the age of 17, and it is of relatively proper efficiency for wood production. Therefore, the studied region can be considered as a good site for plantation according to the provided product table by Usta (1991).

It should be noted that this stand has been affected by drought in the middle of its age (Ostakh, 2013) which has affected the process of growth stand and has reduced volume growth in the region under study in comparison to other regions of Iran with similar ecological conditions (Yousefi et al., 2013; Sadegh Zadeh Hallaj and Rostaghi, 2011).

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CAI and MAI became equal after 24 years and it can be inferred that MAI reaches its peak at this point (*Table 2*). This peak point varies owing to different site conditions (Engindeniz, 2003). The optimal rotation age which was calculated through the stated method relies entirely on biological information.

Faustman model is the best method for determining the optimal rotation age due to considering the opportunity cost of land as well as opportunity cost of stand (Newman, 1988; Pearse, 1967). It should be noted that the optimal rotation age, calculated by Faustmann model, is shorter than the optimal biological rotation age because of considering economic parameter. Various factors contribute to the optimal rotation age including site quality (Marutani, 2010), carbon subsidiary and tax (Kooten et al., 1995), fire risk and discount rate (Pasalodos, 2010), establishment costs and interest rate (Mohamadi Limaei et al., 2011; Alvarez and Koskela, 2003), non-monetary benefits of forest (Hartman, 1976) and these factors change extensively in various conditions.

According to Petit and Montagnini (2004), determination of optimal rotation age and estimation of the amount of wood produced at that age is necessary for forest sustainability and management; therefore, this issue was taken into consideration. In recent years, farmers have used poplar species around their farms and most of the research in this area has been conducted to determine the optimal rotation age of this species. Coniferous species are planted and utilized by farmers to a lower degree, while a large volume of paper pulp of these species is imported from other countries (Adeli et al., 2012).

According to the studies carried out in Iran, *Pinus brutia* is a suitable species for foresting and restoring of forests in Iran owing to its ecologic conditions which are similar to *Pinus brutia*'s native country; therefore, this paper investigated this species in terms of economic conditions. According to the results, the age of economic rotation in Khorramabad was found to be between 18-23 years.

It must be noted that the studied region is classified as a good site because this species has a relatively suitable growth rate and short optimal rotation age for plantation in this area. It is proposed that other parts of Iran especially those with suitable conditions be investigated in order to avoid a huge currency outflow which occurs due to importing the paper pulp of coniferous species.

Owing to the limitations in wood extraction from Iran's forests, it seems necessary to plant fast-growing species in order to solve the problem of wood shortage.

In this study, factors contributing to determination of the optimal age using Faustmann model such as price and increment were considered constant. As a future line of research, it is recommended to compute the optimal age by considering stochastic states.

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