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A Review of Selected Methods to Determine the Economic Value of Forest: Polish Research

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<http://dx.doi.org/10.5772/intechopen.72907>

Abstract

Value is a multifaceted term, and for this reason, forest economics uses a set of various categories of forest value. Two basic categories of value, with which we deal in economics, are connected with market value and non-market value. Market value is specified by the market as a result of interactions of supply and demand. Occasionally, market value is referred to in Polish literature as exchangeable value and value in exchange. Non-market value is a value ascribed by consumers to a good or service, for which there is no real market. In such cases, many methods have been used over the years to appraise the value of forests. This study presents a synthetic review of scientific thought connected with forest valuation. Concepts of static and empirical schools are discussed, indicating the role of Polish scientists in the development of forest economics in terms of forest value appraisal.

Keywords: forestry economics, forest value, statics, forest rent, empirical methods

1. Introduction

Analysis of historical interactions of man and forest indicates that forestry is a form of land use that supplies a vast array of diverse benefits. A comprehensive set of these benefits is defined as forest functions. Their range and level depend both on forest character and the adopted forest management system [1]. Identification of individual forest functions is the task of both the fields in forestry sciences and economic practice, resulting in the practically unlimited diversity of these functions and multitude of criteria for their classifications. However, the dominant aspect is connected with needs and expectations of individual groups and entire societies [2]. From the point of view of spatial management, forest combines four types of space: natural space—comprising nature elements creating conditions to sustain life of various species and having an ecological value; social space—i.e., occupied by individual communities, which

strive to satisfy their needs, as a result of which it acquires social value; cultural space—as an area, in which heritage of material culture is embedded, thanks to which space is assigned cultural value; and economic space—in which economic activity is conducted, thanks to which space acquires specific usability, utility and economic value [3].

Efforts to give forestry a rational economic basis are almost as old as regulated forestry itself. During the last two centuries, many well-known forestry scientists and practitioners have worked on this topic [4]. Valuation of assets is a significant element in contemporary politics and in economy. Literature on the subject presents several definitions of value. When talking about “value”, the term should either be specified or be understood as an “umbrella concept”, comprising several incommensurable types of values [5]. Within the broader sense of “value” in relation to environmental aspects, it was analysed, e.g., by [6] and [7].

We need to stress the fact that the concept of economic value itself is ambiguous. It may be assumed that in forestry we deal with at least two basic categories of economic values, i.e., the current forest value (consumer value) and expected value. The former value is the commercial value of the entire forest to be felled and sold. It is forest value understood as capital allocated to provide periodical income, with the income already existing. In the latter case when we determine the expected value of a forest, it does not provide any income yet or this income is only partial. The complete income from that forest may only be expected in the future and its capitalised amount at present makes it possible to estimate the current expected value of forest. The above approach to forest value may be classified to the area of material value, treating forest as an economic object. Within this approach, we may distinguish directions, which base value directly on manufacturing or production costs (the concept by Smith from 1776), costs of reproduction (the concept by Carey from 1859) or the price of labour (the concept proposed by Marx in 1867).

Apart from the object-based school in the history of forest valuation, we may also distinguish a subject-oriented trend. It was represented by such researchers as [8–12], Wiëser [13] and primarily [14]. The subject value theory is inseparably connected with liberalism. It was initiated by the first representatives of social economics, fathers of the Austrian, French and German schools based on the so-called marginal utility theory. Proponents of the subject-based forest value indicated the need to establish value in view of individual economic goods in relation to human needs. For this reason, this school of thought considered the aspect of utility as the capacity to satisfy needs of a single individual (consumer).

Representatives of post-classical economics have formally proclaimed ideas of classical economics, but with their attempts to order and develop its theses, they have also simplified its essence. The primary representative of post-classical economics J. B. Say, when investigating economic phenomena disregarding social relations of production, treated economic processes as a specific form of barter, i.e., an exchange of services between production factors participating in economic activity. Say was of an opinion that utility, i.e., the upper limit of exchange value, is the source of value of a good. The lower limit of exchange value is connected with production costs, which following A. Smith he considered to be equivalent to the cost of wages of production factors. In the case of local competition, the market mechanism approximates the market price to production costs. In turn, the share of individual production factors in the realisation of the newly produced value is equivalent to their contribution in the generation of this value. It needs to be stressed

that in this concept all production factors have the capacity to generate value. Say linked the process of generating the utility value with the general process of value formation [15].

A Polish scientist, Stefan Studniarski [16] adopted the economic theory of value proposed by Liefmann in 1917 to the needs of forest economics and distinguished the objective and subjective value in forestry. He claimed that the objective value is a technical term, since it defines technical usability of a good or product and provides essential information from the economic point of view. In turn, subjective value defines the relative attitude of a given subject to a specific good. As such, it is developed in the emotional sphere, and outlays incurred to produce this good are not the primary foundation for its valuation. At present, in forest economics, we may distinguish the economic value and the non-economic value of forest, which directly corresponds to the division proposed by Studniarski.

As we can see, the concept of value has been changing with time. As a result, it has contributed to methodological changes in the foundation for forest valuation, particularly since the concept of valuation is directly connected with value. Valuation is the process of value attribution; every valuation is based on a specific ethics determining the value system applied and uses its own 'language of valuation' [17, 18]. The most typical valuation is connected with the monetary representation of value. Monetary valuation of ecosystem services is a widely used approach to quantify benefits supplied by the natural environment to the society [19].

The greatest interest in forest valuation was observed around the 1850s, when capital was acknowledged as the dominant production factor and forest land was considered to be the only capital engaged in forest production. At the same time, the adopted sustainable and continuous utilisation of timber resources limits forest market turnover. This results in the disturbance of its market prices. In such a situation, valuation methods were developed for forest land and stand based on income generated by forest income from timber sales.

Also in Poland, forest economics has focused on the problem of forest valuation, particularly after WWII in relation with the transformation of the socio-economic system and the adopted different approach to valuation of forest resources. Within the last 30 years, the concept of forest management has again been changed. The former raw material model has been replaced with multi-functional economy. This also determines the development of general concepts in contemporary forest management and thus—also methods to value forest resources. These methods aim at the establishment of a comprehensive appraisal of natural resources, i.e., material and non-material components, in order to improve their condition, to ensure their protection and stewardship in accordance with the principles of sustainable and multifunctional forest management. Apart from the productive function (as a source of raw materials), forests also serve diverse non-productive functions (not related with raw materials): protective, recreational and health-promoting. As it was stated by [20], in Poland, these functions are not marketable goods. For this reason, in Poland as well as many other countries, purchase and sale transactions are very rarely conducted in practice. So far, there are no universal solutions facilitating appraisal of the economic value of forests in such a situation. Over the years, attempts have been made to create solutions connected with valuation of forests. Generally proposed methods of forest valuation may be divided into two basic groups, i.e., based on a static notion of forest, and empirical, within which methods based on tables of stand value

coefficients have been developed in Poland. Thus, Polish researchers have contributed to the still on-going search for methodological solutions connected with forest valuation.

2. Static methods of forest valuation

The problem of a static approach to forests has been discussed for years, e.g., [21–25], Mohring (2001) and [26]. In the history of forest economics, the period of intensive development of the so-called forest statics may be described as the classical period, since it was influenced by the liberal free market economics of Adam Smith in the form of the science on appraisal of forest value and profitability of forest holdings based on a static notion of forest. It was the period in the development of economics concerning forest management starting in the first half of the nineteenth century. It has provided theoretical foundations for the valuation of forest value and profitability in forestry [27].

The period of the so-called static approach to forest valuation was connected with changes in the concept of the objective of forest production. At that time, the material function of forest production was predominantly an economic function. The idea of sustainable timber harvesting was replaced by the objective of ensuring maximum income on capital invested in a forest holding, a concept consistent with the spirit of free enterprise. This was manifested in the idea that “the task for foresters is to obtain the possibly high financial income from the forest rather than the greatest timber volume” [Heeg [28]]. This objective was predominant in forest management systems in many countries for the next 150 years. It was manifested in the mathematical form in the well-known formula of economic equilibrium by M. Faustmann used to determine such age of stand (u), at which income from timber harvesting (D_u) would be equal to the cost of compensation (payment) of land capital (B), represented by interest on that capital calculated for the period, over which it was frozen in forest production [29]. Faustmann’s basic economic equilibrium formula, published in 1849, influenced the economic model of forestintermediate management for many years:

$$Au + \sum D_n \times 1.0 p^{u-i} = B \times (1.0 p^u - 1) + C \times 1.0 p^u \quad (1)$$

where Au is the netto income (cash unit/hectare), D_n is income (revenues - costs) from using the forest before the harvest period, B is the value of land capital (cash unit/hectare), C is the cost of forest regeneration (cash unit/hectare), p is the forest interest rate (%) (e.g., for 4%, $p = 1.04$), u is the rotation age, and i is the current age of stand.

As it was reported by [26], a common notion in forest and natural resource economics is that the celebrated ‘Faustmann formula’ was discovered by a young Hessian forester Martin Faustmann in 1849 and that the ‘Faustmann rule’ or the Faustmann-Pressler solution to the optimal rotation age was derived from it a decade later by a distinguished professor of forest mathematics Max Robert Pressler (e.g., [30, 31]). The Faustmann model is well accepted in economics [32, 33], and it has a “myriad” of applications [23] with high practical relevance worldwide [34]; however, in a wide range of communities of forest and environmental scientists, forestry managers and other forestry-related stakeholders, there is still a very sceptical view towards this model.

Deegen et al. [35] claim that the misunderstanding is threefold: first, overexploitation and deforestation are interpreted as a consequence of unrestrained competition and uncontrolled markets. Second, the effectiveness of decentralised coordination of the self-interest actions of individuals will be totally underestimated. Calls for limitation of competition and market controls, i.e., replacing decentralised with centralised coordination, become louder. Third, how can the prices that reflect today's needs know the concerns of future generations? As a result, they later proposed empirical methods, which are discussed in the later part of the paper.

The scientific foundation for the static approach to forests was provided by the model of a normal forest, i.e., a forest holding composed of pure (single-species) forest management units. In the forest static approach, a normal forest is a forest with an adequate model structure, i.e., normal (appropriate) proportions of age class areas, and thus the same normal reserve, growth increment, annual cut, etc. A forest holding with the abovementioned normalcy characteristics in theory guaranteed continuity and uniformity of forest management both in the temporal and in the spatial terms. The static model of a forest holding determined the organisation and management method; more importantly, it determined the methods of forest valuation and assessment of profitability for that forest holding. It defined the forest holding as a planned system of concurrent activities, which over a certain period are to supply staple goods required to satisfy human needs. In the static forest approach, a forest holding is not an actual entity, but rather purely abstract (the so-called normal forest), not present-day, but based on expected effects in the distant future and not constituting a finite whole, but a mechanical set of individual stands. Forest itself was treated as capital, which had a primary task to generate income for its owner. In view of the above, methodological discussions on the appraisal of forest value based on the static approach were founded on the assumption that forest needs to be treated as capital, as if it was deposited in a bank and from which a certain amount of interest is due.

Finally, representatives of the static approach calculated land value mainly using Faustmann's formula [29]:

$$B = \frac{A_u + \sum D_n \times 1.0 p^{u-i} - C \times 1.0 p^u}{1.0 p^u - 1} - \frac{V}{0.0p} \quad (2)$$

where V is the annual cost of forest administration; the other denotations as previously.

This formula became the paradigm of the approach to forest valuation, assuming forest to be a static entity as well as the foundation for the theory of the highest ground rent, understood mathematically as the interest on forest soil capital. We need to stress here that this formula was based on the so-called static assumption that forest economics is based not on an already existing stand created by nature, but unforested land. This led to a further assumption that interest on capital, such as land (B) and interest on administrative capital (involved labour) (V), was treated as production costs, which should be covered by net income. In turn, net income was determined from the difference in gross income and expenditure deferred to stand rotation. In the estimation practice, representatives of the static valuation school most frequently used approximation formulas for income forest value (formulas by Höninger, Riebel, Glaser).

It was also attempted to determine land value based on incurred costs for the establishment of tree culture and costs of land purchase. For example, Heyer, on the basis of Faustmann's

formulas (Eq. (2)), proposed determination of land value in relation to the land purchase price and costs of establishment of a forest plantation on that land. This assumption was expressed in the following equation:

$$B = K \times 1.0 p^i + \frac{C \times (1.0 p^i - 1)}{0.0p} \quad (3)$$

where K is the capital (land purchase price); the other symbols as previously.

Considerable contribution to the further development of this scientific school was provided by a Polish scientist, Stefan Studniarski, who pointed to the fact that in the case of the income-based method of forest land valuation, this value is established by discounting the value of the product (such as timber in forestry) reduced by forest regeneration costs deferred over the entire rotation period. As he stated, in this situation, the following assumption has to be true: the value of future utility (timber harvested over the entire stand cycle) may be calculated at the time of stand regeneration based on these costs and the assumed forest interest rate. However, this is not the case, since the value of this product is modified not by the incurred costs and the assumed forest interest rate, but rather by the sale prices of individual dimensional timber grades. The abstract character of the concept for the income land value completely disregards actual processes of exchange of goods and services.

In the case of stands, their value was calculated by determining the present value of expected pure income from one rotation cycle. In this case, investigations within the static approach were based on a mathematical formula proposed in 1854 by Oezel:

$$HE = \frac{Au + \sum D_n \times 1.0 p^i - (B + V) \times (1.0 p^{u-i})}{1.0 p^{u-i}} \quad (4)$$

where HE is the stand value; the other symbols as denoted previously.

The above formula was modified by Heyer, who proposed calculation of stand value based on the sum of present values of all costs (the value of land and human capital) less the value of potential income.

$$HE = (B + V) \times (1.0 p^i - 1) + C \times 1.0 p^i - E \times 1.0 p^i \quad (5)$$

where E is the present value of potential income obtained from the forest; the other symbols as denoted previously.

Also in this case, the same Polish scientist, Stefan Studniarski, indicated that from the economic point of view all applied cost items (soil (B), management costs (V) and forest regeneration (C)) are abstract and as such they are of little use in accurate valuation.

Representatives of the static approach to forest valuation were also familiar with the concept of sale value of the stand, which later lost in importance. The sale value of land was considered to be such a value, which a given land plot has in relation to sale of its land and analogously, it was proposed to determine the sale value of stands by comparing it with other such transactions. However, as it was observed earlier, it was problematic since such comparisons were sometimes impossible. For this reason, capital solutions connected with economic forest

valuation should be considered when developing theoretical foundations for forest valuation. This is particularly important, since—as it was shown by Paua Anthon Samuelson, awarded the Alfred Nobel Bank of Sweden prize in economics—the Faustmann concept concerning forest valuation may be applied also in new areas of economic activity (Plotkowski [36]). Stand value may be estimated by capitalisation of cash flows and updating the future (expected) revenue and net costs. Applying the theory of money value, we may determine the value of a stand at any specific age (NPV) as a sum of updated (to that age) net cash flow (NCF) in individual periods (years) of its life (Zajac and Swietojanski [37]). Net cash flows constitute the difference between future revenues and costs of their generation and discounted interest:

$$NPV_i = K_0 + \sum_{i=0}^u \frac{NCF_i}{(1.0p)^i} \quad (6)$$

The Faustmann theory of discounted cash flow analysis was presented by [25]. They described three valuation approaches: compounding costs, compounding discounting annuities and discounting future cash flows [25]. At present, the method of forest value estimation is not a problem. It is rather the determination of an adequate interest rate.

Apart from the concept to treat forest as bank capital within the framework of the static forest valuation approach, another school was founded indicating that forest is a form of capital, which had the primary task to generate income to its owner in the form of forest rent. In this case, forest value is directly related to the amount of income, which may be obtained assuming sustainable forest management. The volume of this net income corresponded to capital for a specific rent:

$$r = A_u + \sum D_n - (C + V) \quad (7)$$

where r is the value of net income (rent); the other symbols as denoted previously.

In view of the above assumption, it was proposed to calculate forest value assuming capitalisation of net annual income (rent) according to the formula:

$$W = \frac{r}{0.0p} \quad (8)$$

where W is the forest value calculated based on capitalisation of net annual income; the other symbols as denoted previously.

In forest economics, the above formula is referred to as the capitalisation equation, while the term $1/0.0p$ is called the capitalisation index or valuation index.

The method of determining the value (price) of forest through capitalisation of net income was identical to the method of determining land price, which according to Marx in capitalist economies is simply capitalised income of land lease. The theoretical foundation for this formula was provided by the proportion:

$$\frac{r}{K_0} = \frac{p}{100} \quad (9)$$

symbols as denoted previously.

It results from the equation that the ratio of the value of rent (net income) to forest value (forest capital) is identical to the ratio of the part (percentage) to one (to 100%). The above proportion may be used not only to calculate forest value, but also the value of the rent:

$$r = Ko \times 0.0p \quad (10)$$

as well as the value of interest rate:

$$0.0p = \frac{r}{Ko} \quad (11)$$

symbols as denoted previously.

It needs to be stressed that the valuation multiplier is inversely proportional to the adopted interest rate. Thus the higher the interest rate, the higher the rent, but the lower the value of forest (capital). As a result, we should be cautious when establishing interest rates. The determination of forest value by capitalisation of net income resulted in very low or even negative values for forests currently having no stands. In the mid-1800s, this led to the development of the so-called component methods of forest value estimation. In terms of the approach to forest as a form of capital both in theory and in practice, two schools of rent accounting were developed, i.e., forest rent and ground rent. In the theory of the forest rent, the entire forest, i.e., land together with stands and other property located on that land, e.g., buildings, structures and roads, was assumed to constitute the initial capital for a forest holding. Forest value was calculated by capitalisation of the forest rent, typically annual and perpetual. This method is also called the indirect method, since forest value is calculated from the income generated by the forest. In the theory of the ground rent, both forest land and fixed assets located on that land, i.e., buildings, structures and roads, were assumed to be the initial capital of a forest holding, while stands were treated as products with a long maturation (turnover) period and as such they were elements of working capital. Thus the value of forest land and the value of stands were calculated depending on age. As a result, forest value was composed of two elements, i.e., the value of land and the value of stands. This method is sometimes called the direct or component method.

A significant contribution to forest value estimation using the static approach to forest valuation is connected with the studies by of a Polish scientist, Ostrowski. In 1976, he proposed the determination of the economic value of forests from the quotient of net income and forest interest rate, increased by adding the value of fixed assets involved in production. The result also needed to be corrected by the quality index of the forest holding(s). The example forest holding quality indexes for Poland proposed by Ostrowski ranged from 0.8 to 1.2. The proposed formula took the following mathematical form:

$$Wg = \left(\frac{r}{0.0p} + Wst \right) \times s \quad (12)$$

where Wg is the economic value, Wst is the value of fixed assets engaged in production, s is the forest holding quality index; the other symbols as denoted previously.

In turn, Ostrowski proposed to calculate the level of rent based on information concerning net income, the forest management plan and actual forest management as well as the level of commercial afforestation:

$$r = Dc + (E - U) \times Sp + pz \times w \quad (13)$$

where Dc is the annual net income based on accounting data (net income), E is the annual cut (merchantable timber), U is the volume of harvested dimensional timber grades (merchantable timber), Sp is the mean stumpage price per 1m^3 timber, pz is the area of commercial afforestation (apart from regeneration of current logging sites) and w is the mean costs of reforestation of 1 ha.

The formula proposed by Ostrowski [38], appropriate from the point of view of both accounting and forest valuation principles, could be used in practice, provided an economic equilibrium was found between the value of forest production and costs incurred on the operations of the forest holding. This formula assumed that net income is generated from forest economic activity. As it is generally known, in forestry, this condition is not always fulfilled due to the effect of the differential rent. For this reason, another Polish scientist Podgórski proposed a modification of Ostrowski's formula and replaced forest rent (r) with the value of the annual cut calculated from the product of volume of timber to be harvested in a given year (E) and the stumpage price of a cubic meter of timber (Cnp). As a result, Ostrowski's formula modified by Podgórski took the following form:

$$Wg = \left(\frac{We}{0.0p} + Wst \right) \times s \quad (14)$$

where We is the value of the annual cut; the other symbols as denoted previously.

As it was previously mentioned, the static approach to forest value estimation is not problematic; it is rather the determination of an adequate interest rate that may be a problem. In the case of methods based on the static approach and the percentage or rent calculations, the interest rate is of paramount importance. The manner of its determination has always been considered dubious, as it has not been definitely established whether it should be identical in the percentage and rent calculations. Nevertheless, it was assumed that it should be constant throughout the entire rotation during the stand life. Attempts were made to apply the ordinary interest rate and then compound interest, and subsequently, it was the arithmetic mean and the geometric mean of the two. Finally, it was decided to refer to compound interest, but problems with the adoption of the level of interest rate could not be resolved.

Some literature sources present an opinion that interest rate is a comparative measure, which may be used to determine value, and as a result of such an economic character, it has to be uniform in all valuation cases. A discussion on this subject was presented by [39], who indicated that some researchers, e.g., [40], assumed a constant value of interest rate at 3%. In turn, [41] claimed that the conventional (risk adjusted) discount rate to be applied on farmland investments was 3% and on pure money capital 5%. For this reason, he felt it reasonable to be something in between for forest, thus as an integer, 4%. Lehr and Borggreve [42] were strong opponents of a low interest rate, and for a permanent forest culture, they applied rates of 4–6%, while for less permanent cultures, they applied rates of up to 10%. Some researchers express an opinion that in the case of capital with an extensive productive life interest rate (p) is 1–3% [43]. In turn, Piekutin and Skreta [44] claimed that the level of forest interest rate decreased from 5% in the early 1800s to approx. 1% at present.

In the twentieth century at the turn of the 1980s and 1990s, Polish scientists Podgórski and Kikayi [45] investigated the empirical determination of the volume of forest interest rate (p). They stated that a reliable method to determine the forest interest rate is provided by the annual cutting budget (E_u) in relation to the structure of standing timber resources (Z_{np}):

$$0.0p = \frac{E}{Z_{np}} \quad (15)$$

In financial terms, they proposed to calculate the volume of forest interest rate (p) from the ratio of the value of the assumed yield and the value of standing timber resources.

Podgórski and Kikayi [45] were of an opinion that replacing the category of net income from a forest holding with the volume or value of the allowable annual cut is more consistent with the contemporary forest holding practice, while modified forest interest rates may be used for monetary valuation of both forest land and standing timber resources. In Poland, the forest interest rate calculated in this manner is approx. 2%.

More recently, [46] modified that opinion and proposed calculation of forest interest rate from the ratio of the volume of harvested timber (U), which is currently the source of income, and standing timber resources (Z_{np}), or from the ratio of current increment of forest (P_b), which will be the source of income in the future, and standing timber resources:

$$0.0p = \frac{U}{Z_{np}} \text{ or } \frac{P_b}{Z_{np}} \quad (16)$$

where P_b is the current increment; the other symbols as denoted previously.

For example, in Poland, the increase of forest (P_b) is 60 million m^3 and standing timber resources is 2 billion. It follows that the forest interest rate is 3%.

$$0.0p = \frac{P_b}{Z_{np}} = \frac{60\,000\,000}{2\,000\,000\,000} = 0.03; p = 3\% \quad (17)$$

From the natural point of view, the above formulas for the determination of forest interest rate may be considered rational. Current increment in stand volume is the actual natural effect of forest management, which may generate income in the future. For this reason, it is proposed to call the calculated forest interest rate the natural interest rate. In turn, the degree of forest use, resulting from the allowable annual cut, is the technical effect of forest management, since its volume is determined by the principles of calculation and establishment of allowable annual cuts.

Investigations conducted at the Department of Forest Economics, the Poznań University of Life Sciences (Poland), confirm that from the technical and natural point of view, the forest interest rate ranges from 2 to 3%.

3. Empirical methods to estimate forest value

Empirical methods to estimate forest value were developed as a result of criticism of the static methods voiced, e.g., by Glaser, Höllinger and Köstler. Critics of methods based on the static approach (particularly the percentage methods and forest rents) were of an opinion that using one formula it is not possible to estimate forest value regardless of stand age. This is because when

there are no mature stands there is no income and no rent and there is no simple dependence throughout the entire stand life cycle between income (rent) and costs of running forestry operations and forest value. Thus, with years, representatives of the static approach to forest valuation replaced static formulas for the calculation of stand value with simplified empirical formulas. In the appraisal of stand value, two developmental phases were distinguished, i.e., merchantable mature stands (mainly at rotation age) and non-merchantable immature stands. Later from the group of immature stands, second-growth forests and sapling stands were distinguished as a separate group of stands. Such a division into three groups of stands, i.e., second-growth forest and sapling stands (stands of the youngest age classes), stands of medium age classes as well as mature and overmature stands, is still used in empirical methods. The value of second-growth forest and sapling stands was determined using the outlays method, i.e., based on the sum of all costs incurred on the establishment, tending, protection and other costs paid from the moment of establishment to the moment of forest valuation. Any income from commercial thinning was deducted from this value. This method has not been disputed. However, it is considered objectionable to add up costs over longer periods, i.e., 20–30 years. It is acceptable to estimate the value of mature stands (at rotation age and older). The value of these stands is estimated using the realisable value method, i.e., based on income, which may be attained at cutting the entire stand. The greatest problems are posed by estimation of value in the case of immature stands in medium age classes. For such stands, the so-called expected value is determined. A certain (acceptable) value is the value of mature stands, and for this reason, it has been attempted to reduce (discount) this value using respective indexes to the value at the estimation age. In this respect, Glaser and his followers were most successful. At the initial stage of his research, Glaser assumed that the value of stands changes in proportion to their age. As it was reported by [39] and Podgórski [47], age as the reducing factor was adopted for the first time by Martin. Thus assuming that the age of stand is of key importance for its value, the following proportion was developed:

$$\frac{A_i}{A_u} = \frac{i}{u}, \text{ thus } A_i = \frac{A_u \times i}{u} \quad (18)$$

where A_i is the expected value of estimated stand and A_u is the realisable value of stand at rotation; the other symbols as denoted previously.

This formula, while mathematically correct, provided overestimated results, particularly in the case of younger stands. In further research, it was assumed that stand value changes in proportion to stand age squared. Thus a proportion was constructed:

$$\frac{A_i}{A_u} = \frac{i^2}{u^2} \text{ therefore } A_i = \frac{A_u \times i^2}{u^2} \quad (19)$$

symbols as denoted previously.

In turn, this formula gave overestimated results. Today, we know that there is no simple dependence between the value of a stand and its age or age squared. The third version of Glaser's formula is referred to as the corrected Glaser's formula. In order to eliminate inaccuracies of the previous formulas, Glaser proposed a further correction introducing to the formula regeneration costs for 1 ha forested area (C):

$$A_i = \frac{(A_u - C) \times i^2}{u^2} + C \quad (20)$$

symbols as denoted previously.

Under Polish economic conditions also this formula did not yield satisfactory results. For this reason, Glaser's formulas were adapted to the situation of Polish forestry by Prof. Jan [48]. A significant contribution of Świąder to forest economics in the area of forest valuation is connected first of all with the determination of age class periods, within which respective methods of forest value estimation should be applied. He stated that the reproduction cost method, which replaced the method of generated costs, should be applied to 20-year periods in the case of coniferous species and to 30-year periods for broad-leaved species except for oak, for which it is 40 years. Świąder proposed to calculate the value of stands of that age using the following formula:

$$Wr = (C + Kk \times n + Ko \times i) \times z \times p \times BWP \quad (21)$$

where Wr is the reproduction value of second-growth forest or sapling stands, C is the one-off cost of establishment of second-growth forest, Kk is the recurring costs connected with forest tending measures, n is the number of tending operations, Ko is the protection and administrative costs, i is the age of second-growth forest or sampling stand, z is the stocking index, p is the area and BWP is the site index.

The value of costs included in formula 19 needs to be understood as mean costs for the last three years calculated on a regional scale, rather than a single forest holding. We have to stress here the proposal of [48] to apply the site index (BWP). That researcher rightfully believed that the mean reproduction cost is an equivalent of stand value only in the poorest forest sites. The proposed use of the quality conversion coefficient aimed at the adjustment for the higher value of second-growth forests and sapling stands growing on quality sites. This conversion coefficient is calculated from the product of the growing stock of a mature stand on a site of a given quality class to the growing stock of a mature stand in the site of the lowest quality class for a given species. Data on the growing stock are collected from respective stand yield tables. It needs to be stressed here that in the above formula we do not deal with the cost price (expenditure), but rather the value of forest reconstruction in a given year under specific conditions based on current costs. The use of current costs is a certain form of deferral of costs incurred 10 or 20 years ago, at the time when the actual expenditure was incurred.

Ref. [48] modified also Glaser's formula concerning the expected value and established for that method specific age boundaries. He reported that this method needs to be applied above the limits established for the reproduction cost method, i.e., for coniferous species starting from 21 years to the assumed rotation and for broad-leaved species starting from 31 years to the assumed rotation, while for oak stands from 41 years to the assumed rotation, respectively. Valuation of such aged stands should be performed according to the following formula:

$$Ai = (Au - C) \times \frac{i^2}{u^2} \times z \times p \quad (22)$$

symbols as denoted previously.

Other Polish researchers also proposed their own modifications to Glaser's formula for the calculation of expected value. For example, Trampler proposed to calculate the expected stand value from the following formula:

$$Ai = C + (Au + \sum Du - C) \times \frac{i}{u} - \sum Di \quad (23)$$

where D_i is the value of pole stand to the age of stand at valuation (i) and D_u is the value of intermediate stands to rotation age; the other symbols as denoted previously.

Another Polish researcher [49] was of an opinion that the conversion factor resulting from the ratio of estimation age (i) and rotation age (u) of stands may not be a key element in the estimation of stand value. He argued that labour time is the only inherent condition for forest production operations. For this reason, he believed that an appropriate approach to the valuation of medium-aged forests is provided by the method based on outlays of required labour, which needs to be performed in the process of timber production. A logical consequence of this statement was to limit the entire calculation, using cost ratios, to the potential value by reducing the actual value of a mature stand. For this purpose rather than the coefficient resulting from the ratio of stand estimation age and stand rotation age, he used the ratio of stand production costs to stand estimation age and total stand production costs to rotation age:

$$A_i = (A_u + \sum D_u - \sum D_i) \times \frac{k_i}{K} \times z \quad (24)$$

where k_i is the incurred costs of timber production to age of stand value estimation (i) and K is the total costs of timber production incurred until rotation age; the other symbols as denoted previously.

However, in this method, it is the reduction factor (k_i / K) that causes problems, since in practice we may use solely calculated costs, as actual silviculture costs incurred over a period of several decades are difficult to assess. Moreover, it was assumed in that method that stand value changes in proportion to costs incurred on silvicultural measures; as we know—also from studies outside the field of forestry—there is no simple correlation between incurred costs and the value of produced goods (apart from specific cases).

Another method applied to value mature and overmature stands was based on realisable value. This method provides the actual market value of stands, since it is established based on actual, i.e., market timber prices. For this reason, in practice, it has been considered least controversial. It was assumed that for mature and older stands the value of these stands is equivalent to the value of timber dimensional grades found in the estimated stand less costs of timber harvesting:

$$A_u = \sum (M \times P) - K_p \quad (25)$$

where $M_1, M_2 \dots M$ is the volume of individual dimensional grades; P is the prices of individual dimensional grades; and K_p is the costs of timber harvesting and extraction.

We face problems with the practical application of this method, since in some cases stands of the same species and in the same age are separated only by a compartment boundary or a road, but they differ in their rotation age. For example, 90-year-old pines may sometimes be estimated based on the expected value, since their rotation age was established at 100 years, while in another case, on the basis of realisable value, as their rotation age was determined at 80 years. We know from experience that stand value fluctuates stepwise (it is not a continuous function) with changes in the calculation formula. This is the case when the reproduction

cost method is replaced with the expected value method or the transition from the method based on expected value to that of realisable value. The abovementioned methods of estimating stand value, such as proposed by Prof. J. Świąder, were implemented in Poland in 1963 on the power of the directive of the Ministry of Forestry and Wood Industry (the Journal of Laws Dziennik Urzędowy Ministerstwa Leśnictwa i Przemysłu Drzewnego, no. 4, 1963) [Podgórski [50]].

4. Yield table methods in estimation of forest value

An original contribution of Polish science to research on stand value estimation is connected with the development of stand yield tables. The three methods presented above, i.e., reproduction costs, expected value and utility (realisable) value, were applied at the Forest Research Institute when developing stand value tables for individual types of forest trees depending on their age and site quality classes. These tables were amended and updated several times. They may be extensively applied in practice, particularly in the determination of losses due to premature stand cutting.

As it was reported by [20], for the purpose of yield tables, stand value based on the incurred costs was determined using the following formula:

$$W_{ki} = C + K_z \times n + K_o \times i \quad (26)$$

where W_{ki} is the stand value calculated based on incurred costs; C is the one-off costs connected with establishment of second-growth forest; K_z is the costs recurring several times during stand growth; K_o is the fixed costs, recurring annually; n is the number of cost recurrences K_z to age "i"; i is the age of valuated stand.

The expected value of stands was established using the formula:

$$W_i = \frac{C + (W_u + D_u) - C}{u} \times \frac{i}{u} - D_i \quad (27)$$

where C is the cost of establishment, fill-in planting and tending of second-growth forest; D_u is the realisable stumpage value of pole stand to rotation age u ; D_i is the realisable stumpage value of pole stand to age i ; W_u is the realisable stumpage value of stand at rotation age; u is the rotation age; and i is the age of valuated stand.

Realisable value of the stand was determined using formula 23 given above.

Calculated values of stands were determined using the above mathematical functions and they are given in the form of tables depending on age and stand quality class in terms of 5-year intervals. Tables contained values in monetary units for a fully-stocked stand of 1 hectare. For this reason, these data were becoming obsolete rather fast and needed to be updated. An essential change in the manner of stand appraisal was introduced in the 4th edition of the tables published in 1985, in which it was decided not to present stand value in monetary units; instead, an

arbitrary unit factor (value index) was introduced in the form of “1 m³ 2nd grade pine lumber”. This made it possible to determine stand value with no frequent table updates required to compensate for changes in prices and costs. In the next 5th version of the tables published in 1991, considerable changes were introduced to the method of stand value calculation. These changes were connected with the method to determine value based on incurred costs and expected value. Value based on incurred costs (W_{ki}) was calculated using the following formula:

$$W_{ki} = C + K_p \times n + (K_o + r) \times i \quad (28)$$

where C is the one-off costs connected with the establishment of second-growth forest, K_p is the costs recurring several times during stand growth, K_o is the fixed costs, n is the number of recurrences K_p , r is the forest rent and i is the stand age.

In this version of the tables, the expected value (W_i) was determined using the following formula:

$$W_i = (K_z + r_i) + \frac{(W_r + W_p - K_z - r_i) \times i}{u} - W_{pi} \quad (29)$$

where K_z is the cost of establishment of second-growth forest, r_i is the forest rent at age i , i is the current stand age, u is the rotation age, W_r is the value of timber from mature stand, W_p is the total value of pole stand to rotation age and W_{pi} is the total value of pole timber harvested to age i .

In 1997, due to the change in timber classification introduced in Poland in 1993 and its transformation from use-based to grade and dimension-based, the 6th version of the stand value tables was updated. The previously adopted arbitrary conversion unit of “1 m³ 2nd grade pine lumber” was replaced by a new unit, i.e., “1 m³ softwood lumber”. Moreover, the tables were adapted to amended legal regulations.

In 2002, the next 7th version of the tables was prepared, in which new stand value indexes were established, taking into consideration current timber prices and costs of its production, as well as the new conversion unit, i.e., “1 m³ total timber”. In this version, the respective value indexes are given in terms of 1-year intervals. These tables (the 7th version) constitute an attachment to the currently binding Regulation of the Minister of the Environment of 20 June 2002 and they are the legal foundation for the estimation of losses due to single indemnity for premature stand cutting (the Journal of Laws Dziennik Ustaw no. 99, item 905).

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