EARLY DANISH CONTRIBUTIONS TO FOREST ECONOMICS

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ABSTRACT

Danish forest economists may claim some precedence with regard to the maximum soil rent theory in forestry (the German Bodenreinertragslehre), i.e. the problem of economic optimal forest rotation. As early as 1801, C.D.F. Reventlow outlined that the forest stand must return an incremental rent or otherwise be replaced. Reventlow estimated the present value of the return from the forest rotation, and as a consequence was the spokesman for early and heavy thinnings. A more developed theory on the problem of the forest rotation was presented by J.F. Hansen in 1852, i.e. before the German M.R. Pressler in 1858 made an attack on the prevalent German forest economics. In 1876, J.P. Gram developed and conceptualized Hansen's theory, giving it a more simple and stringent form than that of the Pressler-Heyer-Judeich School. Gram realized that the problem of optimal rotation in forestry is an ordinary economic problem of profit maximization rather than a specific forest economic problem of maximizing the soil rent. Gram's 1876 paper is a seminal outline of the development of forest resource economics later attributed to, e.g. findings of Swedish economists in the 1920s and American resource economists in the 1970s.

Keywords: Bodenreinertragslehre, forest economics, German school of forest economics, optimal forest rotation.

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INTRODUCTION

In the late 18th century, the new German principles incorporated in the high forest system were introduced to Danish forestry. The German influence was mainly in the form of G.L. Hartig's management plans and silvicultural principles, using long rotations and light thinning regimes with long intervals. The Danish Count C.D.F. Reventlow, who held important Government offices around 1800 and

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was himself a forest owner, became acquainted with the German ideas. He was also familiar with forestry in England and France and greatly impressed by the forest science of these countries. As early as 1801, Reventlow outlined an economic theory on the optimal forest rotation. (Grøn, 1960). The theory was in keeping with the emerging general economic ideology (*the liberalism*), which had not yet gained access to forestry.

A theory on the economics of optimal forest rotation was presented by Professor of Forestry J.F. Hansen at a lecture in 1852. It was contemporary with Faustmann's seminal paper of 1849 on the valuation of land for forestry, which, however, did not consider the optimal forest rotation maximizing the soil value. In his attack on the prevalent German forest economics in 1858, M.R. Pressler addressed the problem of optimal rotation. Reventlow and Hansen can claim precedence over the German School of forest economics on the problem of optimal forest rotation.

A comprehensive version of Hansen's theory on optimal rotation age was published posthumously in 1877. One year earlier it had been analyzed and revised by the mathematician J.P. Gram in the Danish Journal of Forestry. By that time similar considerations had been presented by *inter alia* Pressler (e.g. 1859, 1860, 1865 a, 1865 b), Heyer (e.g. 1871) and Judeich (e.g. 1869, 1870, 1871). However, by using the maximum entrepreneurial profit rather than the maximum soil rent (i.e. the German *Bodenreinertragslehre*), both Hansen's and Gram's presentations gain some illumination compared with the German School of forest economics. The German scholars presented forest economics as a specific discipline while the Danes revealed that forest economics is in line with economics of other production sectors. Gram addressed the problem of optimum rotation in forestry as being an ordinary economic problem of profit maximization rather than a specific problem of maximizing the value of forest land. And moreover, he was a pioneer by introducing a dynamic element to forest economics (cf. Hermansen, 1961).

The contributions by Reventlow, Hansen and Gram to forest economics are outlined and discussed in the present paper.

AN EARLY DANISH APPROACH TO INDICATING PERCENT

In 1793 Reventlow made stem analyses on oaks and beeches felled in his forests, and during the following years he had similar analyses made in the Danish Royal Forests. By the scientific standards of the time, these data were unique in making it possible to calculate the annual increment of individual trees and its dependence on the age of the trees, their size and spatial distribution.

The primary object of Reventlow's analyses was to investigate the economics of forestry (Grøn, 1960). His hypothesis was that the economic return from the German regular high forest system could be significantly enhanced if combined with frequent and heavy thinning. As opposed to the view held by most contemporary authors, Reventlow was convinced that forestry *could* make a profit, i.e. yield an interest on the capital invested sufficient to compete with returns from alternative investment. Consequently he advocated that forestry be fundamentally guided by the same economic principles as other sectors. These convictions also made Reventlow consider the economic optimal rotation age. On the basis of his measurements of annual increment Reventlow calculated the optimal rotation age of oak and beech on better soils, using an incremental approach and an interest rate of 4 per cent, which seems to have been the going market interest on capital investment. Reventlow did not elaborate on how the interest rate was determined. A comparison was made with Hartig's yield tables (1804) to demonstrate the economic advantage of heavy thinning regimes.

Reventlow lectured on the subject in 1801 (Grøn, 1960), and in a preliminary report from 1811[1] on his investigations he stated:

> *"In the treatment of forests less care should be taken to obtain the greatest possible growth from individual trees than to develop the whole forest so that it will bring its owner the greatest possible economic return... and bring it to that point where the growth increment of the*

[1] Published as separate prints (Grøn, 1960).

forests will be so great that the owner can find no advantage in felling the forest as the increment shall be worth more than four per cent of the value of the growing trees."

(Reventlow, 1818)[2]

This statement later caused Professor of Forest Economics, A.H. Grøn to say that Reventlow's propositions were half a century ahead of his time:

"The thoughts later expressed in ... Pressler's and Judeich's papers on forest economics, in which the ... Bodenreinertragslehre [i.e. maximum soil rent] ... is formulated, are already found in Reventlow's conception of the object of forestry."

(Grøn, 1960)

Reventlow's reasoning was like this (cf. Oppermann, 1889). A forest stand is mature when the annual increment is decreasing and provides less than 4 per cent of the value of the standing volume. He further made a plea for taking time into account when calculating revenues from forestry, an uncommon procedure at that time. Reventlow's interpretation of his calculations was:

"It appears from these calculations that in a reasonable term of years the income will be so considerable that it will begin to compensate for all his labour and trouble the person who tended such forests, and that the annual growth of the trees and the return from appropriate thinnings will be so large that at four percent rate of interest, it cannot be advantageous to fell the trees [i.e. beech] before they are about eighty years old."

(Reventlow, 1960)[3]

In this marginal approach to the problem of optimal rotation age, an interest on soil value is apparently not taken into account. In that case Reventlow's proposition

[2] Quotation from Reventlow (1960), cf. footnote 3.

[3] When Reventlow finished his work about 1816 he could not afford to publish it. His treatise was not published in Danish until 1879; a shortened edition of his German version of the manuscript was published 1934; and an English translation of his Danish manuscript was published 1960.

corresponds to *the economist's solution* (cf. Fisher, 1930). It is, however, evident from various remarks that Reventlow considered forestry a continuous land-use if managed according to his principles and applying the going market interest on capital investments. In other words, a rent on the soil value was *implicitly* considered in the rate of interest, i.e. of 4 per cent.

Oppermann (1889) holds Reventlow's treatise "the most important work among the older Danish forest literature". However, Reventlow's pioneer ideas were at that time given but little attention:

(i) the preliminary report was published in Denmark's most advanced scientific periodical — "not ordinary reading for Danish foresters", (ii) the completed treatise was not published until 1879, and (iii) the time was not ready for appreciating the new ideas of forest economics (Oppermann, 1889).

Reventlow's contemporaries held that at least state forestry neither could nor should be managed on a profitability basis. They argued that the production objective of state forests was to provide a maximum production of fuelwood and timber, i.e. they adhered to the principle of *maximum sustained yield*. Reventlow did not strongly oppose this but tried to reconcile the differing views by emphasizing the additional benefits to be derived from frequent and heavy thinnings (Oppermann, 1889). Such thinning regime in stands of deciduous tree species was gradually adopted and has later become a distinctive feature of Danish forest management.

THE FIRST THEORY ON OPTIMAL ROTATION AGE

One of the subjects discussed at the 1852 Farmers' General Assembly was: Does sufficient economic reason exist for generally managing beech high forest in long-term rotation? Professor Hansen (1852) outlined his theory on how to calculate the optimal rotation age. A theory which was elaborated in an unfinished manuscript published posthumously (Hansen, 1877). Hansen's successor, Professor P. E. Müller, claimed that the theory was a development of Reventlow's work and that when first presented it was "in some ways ahead of the state-of-the-art in ... Germany" (Müller, 1877).

Hansen's fundamental view is that forestry should be profitable, but he concedes that society considerations may cause deviations from this general rule (Hansen, 1877). He dissociates himself from the prevalent view at that time, viz. that at least state forestry's primary objective is to provide maximum volume of the most valuable wood on a minimum area. The view was widely contended at the 1852 Assembly (e.g. Paulsen, 1852), but Hansen (1852) did not acknowledge any difference in the primary objective between state and privately owned forestry. The discussion reflected the emerging shift in forestry science to the *liberalism* introducing management economics, from the *mercantilistic* view of the forest as a source of sustained physical outputs.

Hansen's theory was a follows. A primary objective of forestry is to provide exactly those wood products which are most needed at minimum costs. He particularly stressed that the production of wood should be viewed as any other production, and therefore he addressed the production costs. The particular fuelwood assortment having the highest *use value* on the basis of heating capacity is used as a *numeraire*, into which the value of the assortments felled at different stand ages are converted. Total accumulated costs at compound interest per unit of the numeraire are calculated for different rotation ages, and the optimum rotation is the age at which unit costs for producing the stumpage are minimized:

$$x_T = \left[(Q+R)\times\left(e^{rT}-1\right)+C\times e^{rT}\right]\times\left[g_T+h_T\right]^{-1}, \qquad (1)$$

where

T = rotation age,

x_T = the time-dependent unit production cost,

Q = the opportunity cost of land,

R = the capitalized value of average annual overheads (effort),

r = compound interest rate,

C = establishment costs,

g_T = the standing volume at age T converted into the numeraire, and

h_T = thinning volumes converted into the numeraire and prolonged to year T at the compound interest rate.

Hansen (1877) presents but few formulas, and he relies heavily on numerical examples. It is notable that in the production costs he includes the compounded opportunity costs of land and effort. He is by and large in accordance with Pressler's theory, though Hansen claims that it "suffers from a certain one-sidedness in that it apparently does not take the local needs into due consideration" (Hansen, 1877). This objection seems to be overdone.

A DEVELOPED THEORY ON OPTIMAL ROTATION AGE

A mathematician, J. P. Gram (1876) revised Hansen's propositions for calculation of the optimal forest rotation. Gram converted Hansen's cost minimization problem into a profit maximizing problem, and he developed a theory on optimal forest rotation with more explicit use of economics than the German school of classic forest economics.

While the Germans use the *soil rent* as point of departure, Gram uses the *entrepreneurial profit*, i.e. the difference between stumpage value at a particular rotation age and its production costs. What follows is an outline of Gram's analysis.[4]

According to Gram, the *costs* for producing *the stumpage value* at the age T for one rotation are the opportunity costs of occupying the land in the rotation period, the capitalized value of average annual overheads in the rotation period, and the establishment costs, less the value of the intermediate income from thinnings. The entrepreneurial profit of *a single rotation* at rotation age T is thus:

$$\pi_0(T) = (V_T + H_T + Q + R) \times e^{-rT} - (Q + R + C), \qquad (2)$$

where

$\pi_0(T)$ = the entrepreneurial profit of one rotation,
V_T = the stumpage value of the standing forest,
H_T = the income from thinnings prolonged to T at compound interest,
C = establishment costs, and
T, Q, R and r, as in (1).

[4] Gram's rather advanced mathematical presentation has been modified and converted to continous time.

The optimal rotation age that maximizes the entrepreneurial profit can be found by maximizing (2), i.e.:[5]

$$\frac{\partial V_T}{\partial t} = (V_T + Q + R) \times r. \tag{3}$$

The growth in stumpage value must earn at least the interest on the employed resources: capital (V_T), land (Q) and effort (R). The optimal rotation age has arrived when this terminal condition is met.[6] Recall that this equation also corresponds with the propositions made by Reventlow half a century earlier.

In the *continuous* forestry the rotation is repeated perpetually. The costs of producing the stumpage value at the end of each rotation are the capitalized opportunity costs of land, the capitalized average annual overheads, and the repeated establishment costs at the beginning of each rotation, less the intermediate income from thinnings. The entrepreneurial profit of a *continuous* forest at rotation age T is thus:

$$\pi(T) = \left[(V_T + H_T) \times e^{-rT} - C\right] \times \left(1 - e^{-rT}\right)^{-1} - Q - R. \tag{4}$$

The optimal rotation age is derived by maximizing the entrepreneurial profit, i.e.:

$$\begin{aligned} \frac{\partial V_T}{\partial t} &= r \times \left(V_T + H_T \times e^{-rT} - C\right) \times \left(1 - e^{-rT}\right)^{-1} \\ &= r \times \left(V_T + \left[(V_T + H_T) \times e^{-rT} - C\right] \times \left(1 - e^{-rT}\right)^{-1}\right) \\ &= r \times \left(V_T + Q + \pi(T) + R\right). \end{aligned} \tag{5}$$

In the classical forest economics the soil value of forest land rather than the entrepreneurial profit is commonly considered, because land is scarce.

[5] Note that: $\partial H_T / \partial T = H_T \times r$.

[6] From (2) Gram derives the same expression for the indicating percent (the Weiser percent) as Heyer (1865), but in a simpler way.

The soil value for forestry (J_T) equals the sum of the opportunity costs of land (Q) and the entrepreneurial profit $\pi(T)$, and adding Q on both sides in (4) yields:

$$J_T = \left[\left(V_T + H_T\right) \times e^{-rT} - C\right] \times \left(1 - e^{-rT}\right)^{-1} - R. \qquad (6)$$

The result reveals that if land can be bought for $Q < J_T$, then forestry can earn a profit, i.e. $\pi(T) = J(T) - Q$. The profit, called the entrepreneurial profit by Gram, is also known as the *differential rent* (Pearse, 1990).

By substituting (6) into (5) the equation is conceptually equal to the maximization of the value of forest land according to the Faustmann formula:

$$\frac{\partial V_T}{\partial t} = r \times \left(V_T + J_T + R\right). \qquad (7)$$

In the classical forest economics the choice of the optimal rotation age has been a strive for maximizing the soil value of forestry. This has led to the presumption that forest economics is somehow a discipline of its own, different from ordinary economics. The early Danish contribution reveals that the optimal forest rotation can as well be derived from the maximization of the entrepreneurial profit. It returns the same result as the maximization of the soil value, i.e. the method credited to the German scholars. The calculation of the soil value assumes a continuous forest. The Danish approach equals the soil value maximization for a continuous forest stand. The Danish approach can also be applied for a single rotation, where the soil value is substituted with the alternative land value (compare (2) and (7)).

Gram gave the economic solution to the optimal forest rotation problem. But since his work was not known outside Denmark, economists in, e.g. Sweden and later in the USA have attempted to develope an *economic* theory of optimal forest rotation. Gram's approach is an early exposition of what was outlined one century later in a seminal paper by Samuelson (1976), who is credited for bringing forest economics in accordance with economics, e.g. by the inclusion of the opportunity cost of land.

Löfgren (1983) has argued that the Swedish economist B. Ohlin had already solved the problem of optimal forest rotation *economically* in 1921, and Löfgren has introduced the concept in resource economics of the *Faustmann-Pressler-Ohlin* solution to the optimal forest rotation problem.

It is striking that the contribution of economics to the problem of optimal forest rotation has provided little but a re-invention of methods already considered and developed within classic forest economics.

It is furthermore noticeable that resource economists refer to Faustmann's formula as the solution to the optimal forest rotation problem, when in fact Faustmann provided a formula for calculating the value of forest land with no attempt to maximize the value through the optimal rotation age. Faustmann's formula is merely the object function for maximizing the soil value, while Gram provided the object function for maximizing the entrepreneurial profit (4).

A COMPARISON OF THE TWO EARLY DANISH APPROACHES TO OPTIMAL FOREST ROTATION

Gram (1877) initially pinpointed the flaw of *a priori* assuming that Hansen's least-cost approach leads to highest profit, and he asserted a certain bias in the optimal forest rotation minimizing the costs of producing the stumpage. Gram shows that it is only when the unit costs and unit value of the numeraire are equal (i.e. a zero profit) that Hansen's method of cost minimization yields the same rotation age as the method developed by Gram.

Gram's expression for the entrepreneurial profit for a single rotation (2) can be rewritten so it is based on the numeraire, i.e.: $V_T + H_T = [g_T + h_T] \times p$, where p is the unit value of the numeraire. Hansen's expression for the unit cost of producing the numeraire (1) can be substituted into Gram's expression for entrepreneurial profit for a single rotation (2):

$$\pi_0(T) = (g_T + h_T) \times (p - x_T) \times e^{-rT}. \qquad (8)$$

The entrepreneurial profit (8) is maximized:

$$\frac{\partial \pi_0(T)}{\partial T} = 0$$

$$= \frac{\partial x_T}{\partial T} = (p - x_T) \times \left[\frac{\frac{\partial (g_T)}{\partial T}}{(g_T + h_T)} - r \right] \qquad (9)$$

If $\partial x_T/\partial T$ is zero the unit production costs are minimized (assuming it is a global minimum). From (9) Hansen's optimal rotation age is shown also to maximize entrepreneurial profit *if* the r.h.s. is zero. This happens if the unit price of the numeraire equals the unit production costs ($p = x_{min}$) *or* the growth in the numeraire (growth in standing stock had there not been any thinning) equals the interest rate. The latter is a special case not discussed further.

The result suggests that Hansen's optimal rotation age equals Gram's when profits are zero ($p = x_{min}$), i.e. when the compound interest equals the internal rate of return. Gram shows that the optimal *profit maximizing* rotation age is shorter than the rotation age estimated from *cost minimizing* when there is possibility to earn a profit ($p > x_{min}$) above the charged overhead for efforts (R).

Gram maintained that as the unit production cost (x_{min}) of the numeraire will not deviate significantly from average stumpage price when the effort (R) is included, the difference between optimal rotation age as calculated according to Hansen and Gram, respectively, will be of no account to forestry practice. The same would be the case if the market for forest land and other production factors was completely efficient.

CONCLUDING REMARKS

Under the influence of the general economic ideology, *the liberalism*, early forest economists like Pfeil (1820–21) and Hundeshagen (1821) laid the foundation for the maximum soil rent theory. Pressler (1858) is generally accepted as the founder of the theory, but its basic formula was developed by König (1835) and improved by Faustmann (1849), and other Germans like Heyer (1865), Judeich (1869) and Endres (1894) contributed substantially to the theory.

The early contribution to forest economics has also been described in Sweden. According to Dickson (1956) the theory was introduced to Sweden by Holmerz (1876), and later important works were here made by Heckscher (1912) and Ohlin (1921). The Swedish contribution succeeded Gram's paper, but it was anyhow considered to be a new re-orientation of forest economics developed in Germany towards economics.

An overview of the early important works in forest economics is given in Table 1, aiming at throwing the Danish contributions into relief. The list should be considered neither exhaustive nor indisputable, and we have only included Germans, Danes and Swedes.

Reventlow's work is probably the very first version of the marginal analysis behind determining the economic optimal rotation age of the individual stand. When Pressler made a consistent development of this approach it had already been deduced by Pfeil and Hundeshagen. The soil value formula had been developed by König and improved by Faustmann by taking the establishment costs correctly

TABLE 1. EARLY IMPORTANT WORK IN FOREST ECONOMICS.

NAME	YEAR OF THEORY PRESENTED	COUNTRY
Reventlow	1811, 1818	Denmark*
Pfeil	1820	Germany
Hundeshagen	1821	Germany
König	1835	Germany
Faustmann	1849	Germany
Hansen	1852	Denmark*
Pressler	1858, 1859, 1860, 1865	Germany
Heyer	1865, 1871	Germany
Judeich	1869, 1870, 1871	Germany
Gram	1876, 1877	Denmark*
Holmerz	1876, 1878	Sweden
Hansen	1877 (posthumously)	Denmark*
Endres	1894	Germany
Heckscher	1912	Sweden
Ohlin	1921	Sweden

into account. Pressler's works were launched as a harsh attack on the opposition to the view that forestry should compete on general economic terms with other capital investments. Forest economists and practitioners held that the objective of forestry should be maximum sustained volume yield and later maximum sustained cash-flow for the entire forest estate.

Hansen's theory on optimal forest rotation was an earlier, independent and more original version of Pressler's theory. Gram elaborated Hansen's theory by making more explicit use of economic analysis. Heyer and Judeich rectified Pressler's indicating percent, and Endres might be seen as the last prominent advocate of the maximum soil rent theory in its pure version, i.e. the narrow interpretation of the economic objective of forestry. Holmerz was a loyal supporter of the theory developed by Pressler and other German scholars. When the maximum sustained cash-flow theory was launched in Sweden, it was opposed by the two economists Heckscher and Ohlin. Ohlin made a seminal analysis of the subject of optimal rotation age.

Denmark has had its share of the controversy between proponents of the maximum sustained yield or the sustained maximum cash-flow (i.e. the German *Waldreinertragslehre*) and the maximum soil rent (i.e. the German *Bodenreinertragslehre*) (cf. Holten-Andersen, 1990), which resulted in an early development of Danish forest economics, mainly by Professor A. H. Grøn (since 1930) who also gave an impetus to the development of forest economics in the other Scandinavian countries. As shown, the Danish scholars Reventlow and Hansen may claim some precedence in time with regard to the problem of optimal forest rotation. The early German development of forest economics resulted in a common belief that the economics of forest resources is somehow different from ordinary economics, but Gram developed an alternative approach which precedes later contributions of economists to the reorientation of forest economics.

Gram's view (1876) on the role of mathematics in forest economics deserves further attention:

> *"The mathematical formulation has as its main aims just to make calculations as correct and simple as possible and to make it easy to assess the accuracy of the re-*

sults. A mathematically formulated analysis of the relevant — in themselves not very complicated questions — is altogether only of importance as a clear and brief expression of a stringent cogitation of the problems."

Grøn (1931) claims that if Hansen had presented his theory in a widely known language, then Hansen and not Pressler had been renowned for renewing forest economics. Furthermore, Gram's 1876 article could have been a classic in international forest economics literature.

ACKNOWLEDGEMENT

The authors appreciate the comments that Professor J. Eid and Dr. H. F. Hoen made on an earlier version of this paper.

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