**Dissertationes Forestales 212**

# The emergence and early development of forest resource economic thought: From land and forest valuation to marginal analysis and vintage capital models

Esa-Jussi Viitala

Department of Forest Sciences
Faculty of Agriculture and Forestry
University of Helsinki

Academic dissertation

To be presented, with the permission of the Faculty of Agriculture and Forestry at the University of Helsinki, for public examination in Lecture Hall 6 of the Forest House (Metsätalo), Unioninkatu 40, Helsinki, on 11th March 2016 at 12 o'clock noon.

*Title of dissertation:* The emergence and early development of forest resource economic thought: From land and forest valuation to marginal analysis and vintage capital models

*Author:* Esa-Jussi Viitala

*Dissertationes Forestales 212*

http://dx.doi.org/10.14214/df.212

*Thesis supervisor:*
Olli Tahvonen, Professor
Department of Forest Sciences, University of Helsinki, Finland

*Pre-examiners:*
Martin Moog, Professor
Department of Economics & Policy, Technische Universität München (TUM), Germany

Jorma Sappinen, Professor
School of Business and Management, Lappeenranta University of Technology, Finland

*Opponent:*
Ulla Lehmijoki, Docent
Department of Political and Economic Studies, University of Helsinki, Finland

ISSN 1795-7389 (online)
ISBN 978-951-651-514-7 (pdf)

ISSN 2323-9220 (print)
ISBN 978-951-651-515-4 (paperback)

*Publishers:*
Finnish Society of Forest Science
Natural Resources Institute Finland
Faculty of Agriculture and Forestry at the University of Helsinki
School of Forest Sciences at the University of Eastern Finland

*Editorial Office:*
Finnish Society of Forest Science
P.O. Box 18, FI-01301 Vantaa, Finland
http://www.metla.fi/dissertations

**Viitala, E.-J.** 2016. The emergence and early development of forest resource economic thought: From land and forest valuation to marginal analysis and vintage capital models. Dissertationes Forestales 212. 99 p. http://dx.doi.org/10.14214/df.212

This study traces the emergence and development of the fundamental ideas and principles in forest and renewable natural resource economics further back in history than has been done previously. Moreover, it provides an analytical and historical framework that allows one to evaluate this disciplinary progress in a larger context, particularly its connections with the prevailing socio-economic conditions, political ambitions and intellectual movements. The study also examines the historical origins and underlying motivations of some of the most persistent controversies that have circled the economics of forestry for centuries. The main focus is on England and German territorial states since they seem to have played a pivotal role in the development of modern natural resource economics.

It is shown that although commercial arithmetic, compound interest and relatively sophisticated land and other property valuation techniques had been around for centuries, it took relatively long until they were applied in a coherent manner to forestland and standing timber stocks. Early insights about the capital-theoretic nature of forests can be detected in the English pamphlet press in the mid-seventeenth century, but it was John Houghton, an alert English writer on agriculture and trade, who seems to have been the first to explicitly recognize the role of the opportunity cost of standing timber and bare land, first in 1683 and again in 1701, as well as the first to compare the present values obtainable from forestry to those from other forms of land use with valid calculations. This line of modern forest economic reasoning resurfaced in 1730, when his compatriot land-surveyor John Richards correctly determined the value of a forest under both intermittent and sustained yield management, thus discovering the essential content of the celebrated “Faustmann formula”.

It was only substantially later that these principles, in line with modern capital and investment theory, were diffused to “scientific forestry”, that is, a more systematic and rigorous form of forestry usually regarded as having been emerged from the mid-eighteenth century in German territorial states. Even in these heartlands of modern forestry, the scholars conventionally credited for discovering the fundamental principles of forest valuation and efficient forest resource management, Martin Faustmann and Max Robert Pressler, had important precursors. Johann Wilhelm Hossfeld appears to have been the first in the German tradition to apply the Faustmann formula, his colleague and contemporary Gottlob König being the first to utilize a marginal method to derive the optimal harvest age for forest stands.

A systematic examination of the political, socio-economic and intellectual factors behind these discoveries suggests that the English scholars at the turn of the seventeenth century were able to excel over their counterparts in other countries because they took inspiration from the novel economic ideas and practices that transformed the contemporary English commercial and financial markets in an unprecedented way. Their personal interest in the economic aspects of forestry, ability to build on established methods of land and other real property valuation, wide intellectual networks and own business activities may explain why they were able to consider forests as a special case of more general intertemporal resource allocation and to apply approaches that in the economics literature have been regarded as of much later origin.

The early German foresters, in turn, were pioneers in building a remarkably coherent resource economic framework that encompassed land values, biological capital and optimal forest management. At the same time they acknowledged that the management of forest capital over time is a particularly difficult task due to the complexity of forest ecosystems, long periods of production, and the associated externalities and uncertainties. These considerations, together with the prevailing cameralistic doctrine that dominated political and economic thinking in German territorial states in the eighteenth century and much of the nineteenth century, led them to develop and to apply such vintage capital models that were based on contemporary envisions of prudent forest regulation, self-sufficiency and sustained yield – visions that perhaps most explicitly materialized in the pertinent quest to construct and maintain a so-called normal, fully regulated or synchronized forest, an archetype of sustained yield forestry that provides an even flow of timber and other forest outputs in perpetuity. These fundamental ideas and premises are readily discernible also in those long-standing controversies that have entangled forest management and planning at different theoretical and operational levels until present days.

Perhaps the most important reflection of the classical German forestry premises is the long tradition that seeks to avoid discounting and strives to achieve a development in which the stream of forest outputs, particularly timber, is non-decreasing at the forest or market levels. Another important manifestation is the persistent claim in forest economics literature that the standard Faustmann model is not valid for fully regulated forests. This dissertation analytically shows that the standard model applies to fully regulated forests under conventional assumptions and the alternative formulations that have been proposed for similar settings are unwarranted from the modern capital and investment theory point of view.

A strikingly similar debate on the nature of capital in sustained yield forestry emerged in the formative stages of the neoclassical capital theory – first at the turn of the twentieth century and again in the 1930s – when some of its renewed pioneers, apparently inspired by the German forestry tradition, adhered to the illusionary view that a synchronized forest represents a permanent and continuous capital fund which eliminates all waiting. This similarity of ideas is just one example of the close intellectual connections between early land and other real property management and modern capital and investment theory, an issue that surfaces throughout the history of forest and renewable natural resource economic thinking.

**Keywords**: forest economics, natural resource economics, Faustmann model, synchronized forest, discounting, natural capital, capital and investment theory, history of economic thought

## ACKNOWLEDGEMENTS

The preparation of this dissertation has been a long and fascinating journey through several centuries and across many countries. I am indebted to all those who have read drafts of the manuscript and provided helpful comments and suggestions during this scholarly endeavour. I am especially grateful to Olli Tahvonen, Ville Ovaskainen, Heimo Karppinen, Jaana Laine and Jussi Leppänen for the valuable advice and many discussions that helped to improve this work. I would also like to thank the pre-examiners of this dissertation, professors Martin Moog and Jorma Sappinen for their valuable comments and suggestions, and professor Moog for also sharing his findings.

The Finnish Forest Research Institute, or the Natural Resources Institute Finland from 2015 onwards, provided an inspiring intellectual environment and excellent facilities to pursue and complete this work. I wish to express my sincere thanks to all my colleagues in these two research institutions who by thought, time and labour have made the preparation and publication of this dissertation possible. The library personnel of the Finnish Forest Research Institute deserve special thanks for their help and advice. The wonderful libraries of the University of Helsinki, furnished with remarkable literature collections and retreat facilities for reading, thinking and learning, provided a special atmosphere and inspiration even on the hardest of days. A special thanks also to Stella Thompson, University of Helsinki, for revising the language of this dissertation.

Above all, I owe an enormous debt to my family, Hannamari, Seliina and Helinä, who have encouraged me during the long process of writing this dissertation and patiently put up with my spending many evenings and weekends alone with books, articles and a computer. The most precious support for this work has originated from their sparkling minds and vivid curiosity that have been constant reminders of what intergenerational perspective, science and life are really about.

Helsinki, January 2016
Esa-Jussi Viitala

# LIST OF ORIGINAL ARTICLES

This dissertation consists of an introductory review followed by four research articles and one manuscript, which are referred to by Roman numerals in the text. The articles are reprinted with kind permission of the publishers.

**I** **Viitala, E.-J.** (2013). The discovery of the Faustmann formula in natural resource economics. History of Political Economy 45: 521–548. http://dx.doi.org/10.1215/00182702-2334785

**II** **Viitala, E.-J.** (2015). Timber, science and statecraft: the emergence of modern forest economic thought in Germany. Manuscript.

**III** **Viitala, E.-J.** (2015). Faustmann formula before Faustmann in German territorial states. Forest Policy and Economics. In press. http://dx.doi.org/10.1016/j.forpol.2015.11.004

**IV** **Viitala, E.-J.** (2006). An early contribution of Martin Faustmann to natural resource economics. Journal of Forest Economics 12: 131–144. http://dx.doi.org/10.1016/j.jfe.2006.04.001

**V** Tahvonen, O., **Viitala, E.-J.** (2006). Does the Faustmann rotation apply to fully regulated forests? Forest Science 52: 23–30.

Esa-Jussi Viitala is responsible for the introductory review of this dissertation. He planned and carried out studies **I–IV**. Study **V** was carried out jointly with Olli Tahvonen who planned the study; Esa-Jussi Viitala participated in the analytics, numerical analysis and writing of the paper. The results were interpreted jointly.

## TABLE OF CONTENTS

# 1 INTRODUCTION

## 1.1 Background

The exploitation of forest resources has been an important issue throughout the history of mankind. Although deforestation continues at an alarming rate, forests still cover 31 percent of earth’s land surface (FAO 2010) and are among the most important natural resources. They produce multiple outputs ranging from timber to biodiversity of flora and fauna, recreational benefits and watershed protection, but sustain life on the earth also more directly by taking in carbon dioxide from the atmosphere in photosynthesis and converting it to oxygen.

Forests and especially natural forests are complex and often fine-tuned ecosystems but from the perspective of modern resource economics they represent biological capital that is produced by the nature and involves the use of land. In this framework the economics of forestry becomes part of the more general theory of intertemporal allocation of resources: today’s consumption decisions, by their impact upon the current stock level, will have implications for future consumption options. The forestry problem thus becomes one of selecting an optimal consumption flow through time, which in turn implies selecting an optimal biological stock level as a function of time (see e.g. Clark and Munro 1975; Clark 1990).

Although the general principle behind economically optimal forest resource use may appear relatively simple, its practical application to real-world situations is a difficult task. Multitude of forest outputs, together with their close interactions and often cumbersome valuation, pose significant challenges for optimizing forest resource management. The task is even more difficult because ecological and economic processes related to forests and their management are inevitably bound up with questions of uncertainty, limited foresight and possibly critical thresholds and typically involve joint-production, externalities and common property. Moreover, they may involve such resources (or their products; goods and services) that cannot be replaced satisfactorily by any other natural, manufactured or human capital. The latter aspect brings forth the formidable question of the role of natural capital in sustainable development, an issue that culminates in the controversy between weak versus strong sustainability.[1]

For centuries, writers focusing on forestry issues have been aware of the multitude and complexity of forest systems and their management (see e.g. Evelyn 1664; Carlowitz 1713). Although many other renewable natural resources are furnished with a similar set of economic-environmental characteristics and functions, it is the extent and combination of these properties that has given rise to the notion that forests are a distinct if not unique form of natural capital.

---

[1] According to the *weak sustainability* view, there is essentially no inherent difference between natural and other forms of capital. In contrast, proponents of *strong sustainability* maintain that man-made (manufactured) and human capital cannot replace all forms of natural capital. Gómez-Baggethun et al. (2010) suggest that the first approach has been mostly embraced by neoclassical environmental economists while ecological economics has generally advocated the latter. The concept of ’critical natural capital’ has emerged as a compromise to signify the part of the natural capital that performs important and irreplaceable environmental and other functions. Imperfect information and diverse preferences (also related to risk) may render this distinction difficult or even impossible.

Consider, for example, the common argument that a forest is both factory and product, a characteristic that is most evident in timber production. It is not possible to peel off annual growth rings from a trunk of tree, instead the whole tree must be cut down to harvest any product at all (e.g. Duerr et al. 1979, 178). Although this property certainly is not restricted to forests, it is the long duration of this interlacing that has traditionally lent support to view forests as a special resource. In boreal and temperate forests the time lag between planting a seedling and final harvesting can be well over hundred years, whereas in many other fields of land and renewable resource use, such as commercial agriculture and fishery, the production period and thus duality property is usually limited to a few months or years.

An important implication of the long production cycle (compared to human life) is that in many cases the forestry problem may become genuinely intergenerational. Private forest owners making long-term investment and management decisions today may themselves never be able to realize the net income and amenity flows that these economic actions are due to generate. It is instead their heirs who shall have the opportunity to collect the benefits or assume for the possible (environmental) losses from the same piece of land. If selling or leasing the land is not an option, the setting implies that owners alive today have to decide how much of the stock to retain for their heirs without actually knowing the preferences and conditions of the future generations. A similar problem relates to the utilization of all natural and man-made resources, but the propensity to long production cycles, irreversibility, life-supporting functions and market imperfections make the problem of intergenerational distribution particularly profound in forestry, both from private and social perspective.

The long waiting also makes the growing of forests a particularly capital intensive form of production. It is difficult to identify similar cases in conventional resource economics dealing with man-made capital goods. Many long term physical investments (e.g. power plants, buildings) require abundance of capital right from the start and the durable assets begin to generate a constant flow of income from inputs immediately or shortly after the ramp-up of production. In forestry, the initial investment to a new generation of forest crop may be relatively small; it is the biological growth process, generating timber and other natural capital accumulation over considerable time periods, that makes forestry and timber production so capital intensive. Clark (2011) notes: "because of the large standing inventory of timber in relation to annual harvest, forestry is perhaps the most capital-intensive activity found in modern economy."[2]

The complexity of forest ecosystems and the relatively long periods of production induce that forest management involves a great degree of uncertainty. At the same time, forests' ability to serve as a storehouse for a multitude of intermediate and final products in living biomass creates considerable flexibility for their management and use. In modern economic terms, forests can be categorized as real options because it is possible to harvest many of their physical outputs also before or after the predetermined (financial) maturity age (e.g. Mezey and Conrad 2010). The most prominent example is standing timber, typically the most important capital component in commercial forests: if the manager makes no harvest, timber volume and value increment usually continue and the accumulated biological capital can be utilized at some later period. Even then, the manager

---

[2] In temperate and boreal forests, the periods of timber production tend to be long due to relatively slow rate of capital accumulation and existence of unit price increments (or even thresholds) in some later phases of the production process. The rotation periods are much shorter in plantation forestry but the great importance of the capital component holds because of the rapid accumulation of timber stock.

may decide to cut only part of the standing stock or, alternatively, allocate forest capital to some other purpose given that for example market conditions or preferences have changed.

Again, the ability to act as a real option is by no means restricted to forests, but in the field of renewable natural resource economics this quality is perhaps most prominent in forestry because natural changes in forest ecosystems are often relatively slow and standing timber is quite resistant against biological depreciation. Other forms of biological capital – for example cereals, livestock, game and fish – typically allow less temporal flexibility in timing and designing harvests. The higher flexibility in forestry can be seen to partially compensate the long waiting until adjustments become possible with a new generation of crop.

Table 1 summarizes some key characteristics of forests and other forms of biological capital from the point of production theory. It is a stylized presentation in a sense that it is based on the primary commercial use of each biological stock in boreal and temperate biomes. Including the whole array of goods and services (incl. amenities) and biomes would provide a much richer picture as it would reveal a greater variety of patterns in the production processes and realization of their yields.

However, the compilation in Table 1 serves as an introduction to the fact that for the last 250 plus years forests have often been regarded as a distinct form of (natural) capital. Accordingly, many scholars and professionals in the field of forestry have been reluctant to cast them outright in the mold of capital and investment theory, whether elementary or modern. This fundamental notion has shaped forest economic thinking and given rise to many of those long-standing controversies that have entangled forest management and planning at different theoretical and operational levels until present days.

**Table 1**. Some key characteristics of forest and other major forms of biological capital (primary commercial use of in boreal and temperate biomes).

| | **Forest stand** | **Field crops** | **Orchard** | **Livestock** | **Game** | **Fish** |
|---|---|---|---|---|---|---|
| Duality in production (stock is both factory and product) | yes | yes | no | yes/no | yes | yes |
| Recurrence of commercial yields | periodic | annual/ semiannual | annual[a] | periodic/ daily | periodic | periodic |
| Production cycle compared to human life (intergenerationality in production) | long | short | short[a] | short/ moderate | short/ moderate | short/ moderate |
| Ability to act as real option (flexibility in timing and designing of harvests) | high | low | low | low/ moderate | low/ moderate | low/ moderate |
| Growing stock movable after commence of production (flexibility in space) | no | no | no | yes/no | yes/no | yes/no |
| Critical life-supporting functions | yes | yes | possible | no | plausible | plausible |

[a] After commence of fruit or nut production.

One of the most persistent controversies concerns the nature of forest capital in sustained yield forestry, a regime that yields a continuous flow of timber and other forest outputs in perpetuity. In the context of even-aged forest management, it implies a so-called normal, synchronized or fully regulated forest – a conceptual ideal that has served as a framework for harvest scheduling, silvicultural tretament and forest planning for the last 200–250 years and relates to more general issues of optimal vintage capital structure.[3]

How land and its biological products ('free gifts of nature') sustaining life and wealth on earth, especially forests and their idealized representations, have been perceived and treated as natural capital over centuries, is the subject of this dissertation.

### 1.2 Previous studies: early constructs of biological capital theory

Although the history of natural resource economics is yet to be written (Pearce 2002, 59), one of the most fundamental insights in the long path toward modern forest and natural resource economics has been the realization that the economics of natural resources has its basis in the economics of capital. This conception was first perhaps implicit and restricted to land and its agricultural products, but over time a similar idea was applied to more complex biological resources with distinct age-class structures and non-market environmental functions, such as forests and fish populations.[4]

The conventional perception in forest and natural resource economics is that the young German (Hessian) forester Martin Faustmann (1849b) captured the capital-nature of forests by showing that the value of forest land can be derived from the discounted net cash flow it is expected to yield in perpetuity. By providing a specification for this fundamental forest economic principle (which became to be known as the 'Faustmann formula'), and by showing how it can be used to derive the value of a forest at any instant and under different future income streams, Faustmann actually put forward a capital valuation method that in general economics has usually been credited to an eminent American neoclassical economist Irving Fisher (1906) (see e.g. Backhouse 1985).

An intriguing finding is that Fisher seems to have been familiar with the early use of the modern capital valuation method in German forestry. In his landmark work *The Nature of Capital and Income* (1906) Fisher points out that classical examples of the principle of capitalization [capital valuation] are

> "young forests, which are worth the discounted value of the lumber they will ultimately form. In Germany and some other countries, such appraisement of young forests is now worked out with considerable precision." (Fisher 1906, 205)[5]

---

[3] A fully regulated forest consists of a series of even-aged forest stands, each of the same area but of different ages. In an idealized case, the number of stands equals the rotation age. Each year the oldest stand is harvested and immediately regenerated. The next year the second oldest stand reaches maturity and is harvested, etc. Thus the forest provides a constant annual flow of timber and other outputs.

[4] The history of environmental economics has been the subject of several surveys (e.g. Kula 2001; Pearce 2002, Sandmo 2015), but these either neglect or contain only a very brief discussion of the emergence and early development of renewable natural resource economics (bioeconomics). A recent historical review on the treatment of nature's benefits – from precursory notions of natural capital to the emergence of the modern ecosystem services research field – also neglects early achievements in forestry (Gómez-Baggethun et al. 2010).

[5] Later Fisher (1930, 55) gave another intriguing example of the connection between income and capital: "the orchard is the source of the apples but the value of the apples is the source of the value of the orchard." Fisher's connections to the German forestry tradition are discussed in section 5.3.

Faustmann (1849b, 443) wrote his celebrated formula originally as

$$B = \frac{E + rD - C(1{,}0p)^u}{(1{,}0p)^u - 1} - \frac{A}{0{,}0p} \tag{1}$$

where $B$ (*Bodenertragswert*) is bare land value, $E$ (*Geldwerth des Haubarkeitsertrags*) income from the final harvest, $D$ (*Durchforstungserträge*) income from thinnings (and $rD$ the value of the latter compounded to the end of the rotation), $C$ regeneration costs, $A$ annual administration costs, $p$ interest rate percent, and $u$ (*Umtriebszeit*) the rotation period.[6] Using modern notation, term $(1{,}0p)$ can be replaced by $(1 + i)$ and $0{,}0p$ by $i$, where $i$ is interest rate. Furthermore, replacing $B$ and $u$ by $L_e$ (land expectation value) and $t$ (rotation), respectively, and denoting $y$ the point of time when incomes $R_y$ and all costs $C_y$ occur, yields

$$L_e = \frac{\sum_{y=0}^{t} R_y(1+i)^{t-y} - \sum_{y=0}^{t} C_y(1+i)^{t-y}}{(1+i)^t - 1} = \frac{\sum_{y=0}^{t}\left(R_y - C_y\right)(1+i)^{t-y}}{(1+i)^t - 1} \tag{2}$$

and equivalently

$$L_e = \frac{\sum_{y=0}^{t} R_y(1+i)^{-y} - \sum_{y=0}^{t} C_y(1+i)^{-y}}{1-(1+i)^{-t}} = \frac{\sum_{y=0}^{t}\left(R_y - C_y\right)(1+i)^{-y}}{1-(1+i)^{-t}}. \tag{3}$$

Equation (2) is a generic form of (1) since all incomes and costs are first capitalized to the end of the first rotation (production period) and then discounted by the term $[1/[(1+i)^t - 1]$ to capture the net present value of an infinite stream of similar net incomes as the first rotation yields. Equation (3) represents the equivalent case in which one proceeds directly to present values.[7]

In modern natural resource economics literature the Faustmann formula is usually presented in a stylized continuous time formulation which captures the present value ($PV$) of a perpetual periodic series

$$PV = [pf(t)e^{-it} - c](1 + e^{-it} + e^{-i2t} + e^{-i3t} + \cdots) \tag{4}$$

where $p$ is timber price, $c$ regeneration costs and $f(t)$ timber (value) growth function. Since (4) is a geometric series, it collapses to

$$PV = \frac{pf(t)e^{-it} - c}{1 - e^{-it}}. \tag{5}$$

Another popular notion in forest and natural resource economics is that the eminent German professor of forest mathematics, Max Robert Pressler (1860) was the first who derived the optimal production period (optimal rotation age or cutting cycle) in forestry by means of marginal approach. He showed that it is optimal to harvest a forest stand when its

[6] Faustmann used $rD$ for compounded thinnings income but $C(1{,}0p)^u$ for compounded regeneration costs. A possible reason for the notational difference is that there were several thinnings and he preferred not to use summation signs.

[7] The first three pages of Faustmann's (1849b) classical article, including equation (1) and notations, are presented in Appendix 1.

marginal value growth decreases under the marginal cost of forest capital (standing timber and bare land) and recognized that this solution corresponds to maximizing land value. The solution is commonly labelled as the ‘Faustmann rule’ or ‘Faustmann condition’ to emphasize the fact that it is a direct derivative of the Faustmann formula. In modern resource economics, reference to the ‘Faustmann model’ is common terminology and encompasses both principles.

The point-input, point-output forestry model introduced by Faustmann and Pressler may easily be treated as a trivial or special case in modern capital and investment theory, but it is actually the building block for *all* neoclassical capital theory. As aptly pointed out by Gaffney (2008), the Faustmann formula ostensibly deals with timber growth but can be adapted to deal with all capital assets, with any time-patterns of inputs and outputs whatsoever. One of its most important applications in even-aged forest management is the flow-input, flow-output production process and its classical case, a fully regulated (steady state) forest that generates a constant and continuous flow of inputs and outputs. This explains the fairly common designation “continuous harvesting”.[8]

Although the economic problem of handling natural resources is as old as civilization (e.g. Lowry 1965), the Faustmann model has been regarded as perhaps the oldest *formal description* of natural resource use that is still considered to be theoretically valid (Tahvonen and Salo 1999). Extending this line of argumentation somewhat further, it has been claimed that Faustmann and his compatriots in German forestry produced a capital theory that outplayed and was developed even earlier than its cousins within the economic discipline (Löfgren 1990; 1995; 2012). Some scholars have even went on to claim that the German ‘forest economists’ in the mid-nineteenth century introduced discounting and discounted cash flows in forestry (Gane 1968) and anticipated marginal analysis (Faulhaber and Baumol 1988; Crocker 1999).

*Faustmann’s competitors in natural resource economics*

In agriculture, the capital-theoretic nature of land, livestock and other productive assets certainly has been recognized for centuries prior to Faustmann, but apparently without developing such explicit resource economic formulations that would be comparable to the Faustmann model (see e.g. Nõu 1967). The very nature of agriculture dictates that the production period is usually one year and thus the time element in production is more or less a technological datum.

The most plausible candidate in the agricultural scholarship to precede Faustmann is Johann Heinrich von Thünen, who in the first volume of his famous *Der isolierte Staat* (1826) introduced a model of agricultural land use (‘location theory’). In essence the model contained similar ideas of diminishing marginal returns of land to those of David Ricardo (1817). In the second volume of the book, worked out during the period 1826 to 1848 and appearing shortly after his death in 1850, Thünen (1850) made his most acknowledged

[8] The other two general types of production are the *point-input, flow-output* case, in which the input of a single date yields output at various future dates; and the *flow-input, point-output* case, in which the inputs are applied continuously through a period of time, leading to an output that wholly matures at a single moment of time at the end of the period. Blaug (1968, 510) and White (2007, 85) attribute these terms to Norwegian economist Ragnar Frisch. The point-input, flow-output case is important in forestry when accounting for wildlife, biodiversity, recreation, aesthetics, watershed protection and carbon sequestration. The flow-input, point-output case is less common but may be applicable e.g. in Christmas tree production, supposing that these trees must be continuously tended.

contributions to the theory of rent and resource allocation based on the principle of marginal productivity.

Thünen’s dedication to agricultural land use and associated wage theory did not divert him from also directing attention to more complex issues of natural resource exploitation. Even the first volume of his book contained a section on forestry (*Forstwirthschaft*) (p. 128–152), but the third and last volume concentrated solely on forestry. The title *Principles for the Determination of the Rent of Land, the Optimal Period of Rotation, and the Value of Timber of Different Ages for Firs* serves as an indication of his ability to distinguish some key aspects of economic forest management and to recognize their interrelations. The volume also contains an explicit formulation for optimal forest management: he maximized land rent and calculated optimal forest rotation of a normal forest, yet erred in evaluating immature forest stands at their immediate sale value (Thünen 1863; for details see Manz 1986).[9]

Since also the third volume of *Der isolierte Staat* appeared posthumously in 1863, consisting of papers selected by his discipline Hermann Schumacher, it is possible that Thünen had documented his insights on the economic aspects of forestry prior to Faustmann. According to Blaug (1990; 1997), Thünen worked in isolation from other contemporary economists and his books were not widely read in his time. In English-speaking academic circles his works did not receive due appreciation until Alfred Marshall (1890) gave tribute to them. This is not to say, however, that alert and economics-minded German foresters could not have been aware of Thünen’s ideas and works, or vice versa.[10]

To fully acknowledge Thünen’s merits in anticipating modern resource economics it is useful to note that he has been regarded as the first to use the calculus as a form of economic reasoning (Schumpeter 1954, 441) and that his calculus models were consistently built up on the premise that a rationally acting farmer strives to attain maximization of the land rent (Nõu 1967, 203). Blaug (1968, 321) goes a step further by asserting that Thünen’s use of differential calculus and marginal reasoning to provide equilibrium solutions of economic variables make him the first truly modern economist.

The aforementioned commentary offers some further indication that early German agriculturists and foresters, particularly Thünen, Faustmann and Pressler, may indeed have played an important role in generating some key ideas and principles of (natural) resource economics.

The question of the use and value of land has connected agriculture and forestry since the early days, but modern natural resource economic interest in fisheries management and aquaculture developed significantly later, perhaps because of the weak property rights and abundance (or hidden nature) of most fishery resources. Baranov (1918) is credited for presenting the first models of fisheries population dynamics but his specifications did not involve economics (see e.g. Quinn 2003). Danish statistician and economist Warming (1911; 1931) was perhaps the first to apply marginal analysis to the problems of common pool resources when he compared the rent available from fishing grounds and land. His contributions went largely unnoticed for a lengthy period because he wrote in Danish, came from outside the core of academic economists, applied an unusual approach to fisheries management and came up with findings and recommendations that were not in line with the

[9] Similar error in valuing young forests at their immediate sale value has recurred in modern forest economics literature, see section 5.3.

[10] First volume of *Der isolierte Staat* appeared in 1826 (revised and reprinted in 1842), first part of the second volume posthumously in 1850, and second part of the second volume and third volume (consisting of a dissertation on forestry) in 1863. Faustmann’s classical article appeared in December 1849.

mainstream (Andersen 1983; Topp 2008). Scott (1955) is conventionally regarded as the first who made an attempt to cast the problem of the management of a fishery resource as a problem of modern capital theory (e.g. Clark and Munro 1975) – over one hundred years after Faustmann.[11]

Treating non-biological renewable natural resources (replenishable resources), such as water and wind, in the mold of modern capital theory seems to be of more recent origin (Griffin 2012). Similar conclusion seems to hold to non-renewable natural resources, such as fossil fuels, minerals and ores. Smith (1982) argues that until early twentieth century economists had mostly ignored the question of the appropriate rate of utilization of non-renewable resources, though scholars like Adam Smith (1776) and David Ricardo (1817) had recognized that relatively favorably located mines could yield a so-called differential rent and Stanley Jevons (1865) had delivered his famous treatment of “the coal question”. What was still lacking, however, was an explicit description of the economically optimal rate of non-renewable resource extraction which Harold Hotelling (1931) was to provide.[12]

The notion that the early nineteenth-century German agriculturalists and foresters may indeed have made some pioneering contributions to modern renewable natural resource economics finds additional support in Bernhard Fernow’s (1902, 415, emphasis added) statement:

> “The economics of natural resources have received only incidental and scanty consideration by *English writers*. The only publication known to the writer which discusses the subject in a broad manner is by G. P. Osborne, ‘Principles of Economics’”.

Vaughn (2006) supports this view by pointing out that although Osborne’s work (published in 1893) was a general economics textbook, it addressed more thoroughly than any other economics textbook the problem of whether the economic system will always make wise use of its natural resources. He suggests that Osborne’s *Principles of Economics* remained the only relevant textbook on natural resource economics for nearly a decade.

A particularly noteworthy observation in this connection is that Fernow refers to *English writers* and makes it clear in other section of his textbook *Economics of Forestry* (1902) – apparently the first on the subject in English language – that he was fully aware of the German tradition in forest economics. This tradition (*Bodenreinertragslehre*) involved modern land valuation and marginal analysis to determine optimal harvests and was condensed in the Faustmann model.[13]

Fernow had this knowledge because, in addition to being one of the leaders of the early conservation movement in the United States, he was a German-born and -trained forester, having background in the famous Royal Prussian Academy of Forestry at Münden. This forestry institute operated in the district of Göttingen, which hosted the famous university with an acclaimed reputation as one of the primary academic melting pots of German and British scholars since the mid-eighteenth century (Biskup 2007).

---

[11] A close examination of Warming’s articles reveals that by 1931, at the latest, he became aware of the extensive use of marginal analysis in forestry as he cited a Danish textbook on forest economics (*The General Theory of Forest Economics*) published in the same year by Howard Grøn (see Warming 1931).

[12] For a more detailed discussion of the development of the economics of exhaustible resources in the one hundred and fifty years prior to the publication of Hotelling’s paper, see Robinson (1989) and Kula (2001).

[13] Consider, for example, the following passage by Fernow (1902, 213): “The true financial rotation is that which brings the highest rate of interest on all the capital invested in soil and stock of wood, or, as it is technically known, the rotation of the highest soil rent or “soil expectancy value” (Ger. Bodenerwartungswerth).”

*Faustmann's precursors in forest economics*

Considering the apparent landmark role of the Faustmann model in modern natural resource economics, or perhaps even in more general resource economics, its intellectual origins have received relatively little attention. Previous studies have examined the development of the capital-theoretic approach to forestry almost exclusively within the space of a few decades *after* Faustmann and Pressler (Löfgren 1983; 1990; 1993; 1995; Löfgren and Mattsson 1995; Helles and Linddal 1997). An interesting observation in this connection has been that, as early as the 1810s, a Danish count Christian Reventlow was performing calculations on the optimal rotation age of oak and beech, using an elementary marginal approach, yet without accounting for the opportunity cost of bare land. Also Thünen (1826, 149; 1966, 121) initially proposed a similar method and solution to determine the optimal felling time of a tree or a forest stand. Although Thünen's remark was very brief, Hall (1966, 121) suggests that it was his first approach to the principle of marginal revenue productivity.[14]

The aforementioned findings indicate that some continental scholars, such as Reventlow and Thünen, both estate owners and keen experimenters in forestry, were aware of the capital nature of standing timber and its opportunity cost several decades before Faustmann, who began his forestry studies at the University of Giessen (Hesse) only in 1841. It seems evident that they preceded Faustmann and Pressler also in their attempts to apply marginal approach to the optimal harvesting problem. Further support for this line of argumentation is offered by the classical forestry literature which contains remarks that variants of the Faustmann formula and Faustmann condition had been put forward a few decades before Faustmann and Pressler by another competent German forester Gottlob König (1813; 1835). For an early commentary on this matter, see e.g. Heyer (1865; 1871) and Schwappach (1888, 821).

Recent research has provided indication of even earlier revelations in modern forest economic thinking. Moog and Bösch (2013) point out that forest valuation under sustained yield management had been discussed and applied decades prior to Faustmann by the Prussian high forest councillor and prominent forest scholar Friedrich von Burgsdorf (1796). His extensive textbook included two numerical examples of calculating forest values under perpetual annual series of income. As described by Moog (2012) and Abel et al. (2015), similar mathematically elementary but theoretically solid calculations on the capital value (*Kapitalwert*) of forests were reiterated and extended in subsequent years by a group of lesser-known German scholars and civil servants, for example von Jordan (1800), Krug (1805), Montanus (1807), Anonymous (1807) [nom de plume "E."], Krause (1812) and Kröncke (1813).

Still predating these accomplishments, Hans Dietrich von Zanthier (1764) and somewhat mysterious writer di Paprica (1789), who signed his work with initials C.J.M. v. C.P. (Count Constanze di Paprica), had presented calculations on the profitability of various forest management regimes and economic returns of forest capital, though the validity of these calculations has remained open. Endres (1911, 183) writes that Zanthier's calculations

[14] For this brief statement, Thünen has been designated in forestry (rather narrowly) as belonging to the group of famous economists who have posed the so-called single rotation solution to the optimal forest rotation problem – others include e.g. William Stanley Jevons, Knut Wicksell, Eli Heckscher, Harold Hotelling, Irving Fisher and Kenneth Boulding (for details, see e.g. Gaffney 1957; Samuelson 1976). The opportunity cost of bare land in forestry has been neglected also in some modern economics textbooks, see for example Alchian and Allen (1983, 122–123) and Varian (1996, 210–211).

were appropriate (*zweckentsprechend*) but does not provide any analysis that would support this proposition. Deegen and Seegers (2011) refer to di Paprica but without details.

The origins of classical forestry are predominantly German, but extending the relevant inquiry to cover the parallel development in the British Isles has opened new perspectives to the question of the origins of the Faustmann formula and condition. Scorgie (1996) showed that an Exeter land surveyor and accountant, named John Richards (1730), had calculated forest values under both intermittent and sustained yield management using discounted cash flow to infinity. Thus Richards can be said to have expounded the Faustmann formula more than hundred years before Faustmann. Another compatible finding is that the English agriculturalist William Marshall (1808) had put forward the fundamental idea behind the optimal cutting rule (Faustmann condition) well before König, Faustmann and Pressler, though only in a brief statement (James 1981, 176–177; Scorgie and Kennedy 1996).

While the above studies have increased understanding of the early development of forest and natural resource economic thought, they also lead to several interesting questions:

- Where did Richards and Marshall derive their modern ideas of forest valuation and optimal forest rotation? Did they have any predecessors?
- What were the key political and socio-economic factors and intellectual movements that induced these insights in England?
- Is it plausible that the fundamental principles related to forest valuation were only introduced in German classical forestry literature almost a hundred years after they had been discovered in England?
- How were the novel economic ideas of the capital nature of forests and their efficient use integrated to the strong German cameralistic tradition with high ambitions to control and regulate economy and its resources?
- What effects has the integration of these quite divergent intellectual orientations had in forest management and planning at different theoretical and operational levels over the last 200–250 years?

In addition to providing answers to these questions, a systematic and rigorous examination of the emergence and early development of modern forest economic thought could increase current understanding of the role of forestry in generating some fundamental ideas and principles of modern natural resource economics. The examination could also shed light on the possible common intellectual roots and developmental patterns between modern forest resource economic thought and more general capital and investment theory.

### 1.3 Aims, scope and outline

The purpose of this thesis is threefold. The *first* objective is to trace the emergence and development of the fundamental ideas and principles in forest and renewable natural resource economics further back in history than has been done previously. The *second* aim is to provide an analytical framework that allows one to evaluate the progress of resource economic ideas in a larger historical context, i.e. to connect it to the underlying changes in political, economic and social environment, and to the more general development of economic thinking. The *third* objective is to extend current understanding of the origins and motivations of some of the most persistent controversies that have entangled forest management and planning at different theoretical and operational levels until present days.

The summary section of the thesis is organized as follows. The second section presents the analytical framework, methods and sources. It also describes the research process; its principles, guidelines and chronological order.

The third section delves back through several centuries to explore different historical stages and transitional periods in regard to the application of some fundamental principles of modern forest and natural resource economics. The section begins with a description of the early development of commercial arithmetic, also outlining the long transition from simple interest to compound interest. Then it moves to examine the origins and development of income stream valuation methods that were used in setting a price for annuities and their close variants *census* and *rente* contracts. It was through these contracts that future income streams from a certain piece of land became subject to modern appreciation. The section ends with a description how these valuation methods were applied to real property in early modern England.

The fourth section focuses on the emergence of modern forest economic thought. It begins with a description of the economic discussion that developed in seventeenth-century England and among other things concerned theoretical linkages between interest rate, land value and timber supply. This famous interest-rate-debate – together with the extensive political changes and the rapid commercial and financial development taking place in England in the latter part of the seventeenth century – prepared the way for the rise of remarkably modern capital markets and forest resource economic thinking.

The fifth section examines the emergence and early development of modern forest economic thought in German territorial states, heartlands of classical forest science. It shows how the early forest science and its fledgling sub-discipline forest economics was shaped by German cameralistic tradition with high ambitions to control and regulate economy and its resources, and how modern capital valuation, marginal analysis and vintage capital models found their way into classical forestry. The section ends with an analysis of the possible role of forestry in generating some key ideas and principles of (natural) resource economics.

The sixth section includes summaries of the separate studies. Studies **I–IV** provide new insights into the emergence and early development of forest economic thinking. Study **V** examines one important modern reflection that the attempt to integrate German cameralism and economic liberalism has generated in forest management and planning. Although these two intellectual traditions share a common ambition to maximize welfare over time, their premises how to achieve this goal are highly divergent. In particular, the study shows that the alternative models for continuous harvesting ("marginal model for divisible capital" and "regular model for timber production") that stem from the cameralistic tradition and have been applied quite extensively also in recent forest economic literature, are unwarranted from the modern capital theory point of view.

The summary section ends with a discussion of the similarities of the early forestry models and more general capital and investment theory – an issue that is apparent throughout the history of forest and renewable natural resource economic thinking. Finally, it points out opportunities for further research.

# 2 ANALYTICAL FRAMEWORK, METHODS AND SOURCES

History and economics involve three broad branches of research of which each has a different focus and character (see e.g. Haney 1913; Samuels et al. 2003). The branches can be designated as history of economics, history of economic thought, and economic history.

Research in the *history of economics* (economic science) is usually limited to times during which economic ideas have become distinct, unified and organized. Traditionally there has been one task that has dominated work in the history of economics – that of developing a more complete and more correct understanding of the theoretical creations of those individuals whom history had identified as great or influential economists (Biddle 2003). By far the most commonly adopted approach to answer question of this type has been to examine the published works of the economist in question. The usual starting points have been the works of the French physiocrats, who called themselves *économistes*, and their followers in political economy, the most outstanding examples being, of course, Adam Smith, Thomas Malthus and David Ricardo. A recent example of this type of approach is the study by Sandmo (2015) which examines the emergence and early development of environmental and natural resource economics since Marquis de Condorcet (1776), a French philosopher and physiocrat.[15]

*History of economic thought* usually involves a larger scope both in time and scholarship. It may be defined as a critical account of the development of economic ideas, searching into their origins, interrelations, and, in some cases, their results. Compared to the history of economics, it is more intimately connected to the general intellectual history in a sense that it encompasses an attempt to understand the economic ideas of past thinkers (economists and other scholars, distinguished and lesser-known) and how and why those ideas have developed and changed through time. A marked part of the economic thought has developed before “economic science” or “political economy”, inspired by the preoccupations that the society as a whole or its representative, the government or other authority structure, held.

The historical context against which economic insights and discoveries in the past can be examined and evaluated is offered by the third research programme, *economic history*. It concerns itself with the history of commerce, manufactures and other economic phenomena, and in this course often examines how economies evolve through time. Because of this endeavor, economic history as a discipline is closely related to political and social history.

This thesis falls mostly in the category of history of economic thought but due to scope and methods it also closely intertwines with history of economics and economic history. The thesis builds on the premise that a systematic and rigorous examination of the emergence and early development of forest and renewable natural resource economic thought involves much more than tracing those individuals (“great men” and lesser-known thinkers) who discovered fundamental resource economic principles or played key roles in their dissemination. An in-depth examination also requires that the essential events and

[15] In his useful review Sandmo (2015) fails to mention that many elements within natural resource economics can be traced back to early economic thinking in agriculture and forestry. This legacy is perhaps most easily discernible in land and capital valuation and in the application of marginal analysis to resource allocation. For a review of the early development of agricultural economics, see e.g. Taylor and Taylor (1952) and especially Nõu (1967). Recent surveys of the development of land and agricultural economics also tend to neglect early achievements in forestry (e.g. Kling et al. 2010; Lichtenberg et al. 2010).

stages of this enduring process are placed and evaluated in broader historical context. This kind of larger framework provides a coherent means to describe and explain to what extent the novel ideas and practices related to forest and other renewable resource use found inspiration and were in line with those more general political and economic currents and intellectual movements that were active and shaped contemporary societies and their operating environments.

Recent attempts in this direction in the field of forestry can be found in Lowood (1990; 1991) and Deegen and Seegers (2011) but these studies have examined the emergence and early development of classical forest science and its connections to the rise of cameral science and German state formation. The present study focuses on the development of modern *forest and natural resource economic thought* and extends previous studies in this particular field both in time and space.

The analytical framework of the study is presented in Figure 1. It comprises the main factors and interactions that are assumed to have influenced the development of forest resource economic thinking through centuries. The framework reflects a general perception that although forest economic insights and ideas fundamentally are products of individuals, the political, social and economic forces have provided the general setting in which these ideas have stemmed and taken root. In essence the same forces have also shaped forest resource utilization, even though the importance of each factor may have varied across time and countries from those affecting forest economic thinking.

In the framework *polity* refers to a state or other organized community or body that has administrative or regulative power or mandate over subjects. This entity has varied over time; in ancient times it may have been the local agrarian community or clan, in later periods a city, territorial state or other domain. The government or other similar politically organized unit prescribes laws, codes and other formal authority structures that regulate individual actions. From the point of economic activity, perhaps the most important aspects concern property rights, guaranteed privileges (e.g. taxation and royalty rights, mutual rights, gild systems), contracts (e.g. credit and financial instruments) and personal freedom.

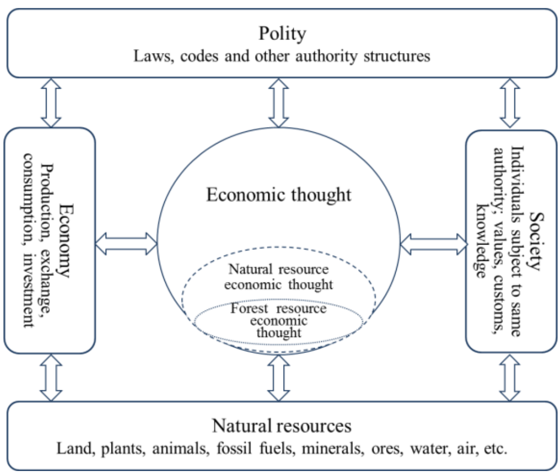


**Figure 1**. An analytical framework for examining the development of forest economic thinking through centuries.

*Society* should be conceived here quite concisely as a body of individuals and their groups that are subject to the same political or other similar authority. The social groups shape individual's identity, values, attitudes and beliefs. It includes also habits, customs, traditions, culture and human knowledge. Societies are conventionally put under three broad categories: pre-industrial, industrial and postindustrial, in which classification the first includes e.g. the agrarian and feudal societies which remained dominant well beyond the medieval period and thus cover most of the time span in this introductionary review. Polity and society are obviously closely interrelated; formal norms regulate individual actions but, reciprocally, informal constraints, traditions and (scientific) knowledge, for example, affect legislation and governing bodies.

*Natural resources* denote land, biological resources (plants, animals and other living organisms) and non-renewables – all distinct in stock, flow and value for each geographical polity, society and economy, and for each period of time. Some natural resources are inextricably connected, for example land and timber, while others, such as timber and ore, may have been at some historical periods complementary, in others substitutive in production and consumption.

*Economy* relates broadly to production, exchange, investment and other economic phenomena. The nature and sophistication of an economy and the distinction between economic life and other spheres of human activity have shown great variance across historical periods and geographical areas. For example, in the early medieval period there was relatively little trade and most goods and services were consumed in the community that produced them without first being sent to market. From about the 1500s trade and commerce increased markedly in Europe and the money economy superseded the self-sufficient or barter economy. The growth of domestic and international markets, the great industrial change and the rise of economic liberalism induced fundamental changes in western economies and their societal and political structures.

Although the analytical framework is based on interdisciplinary approach, through the lens of neoclassical production theory one may perceive society to represent "labor" (services supplied by human beings, human capital) and natural resources to represent "land" (goods and services furnished by nature, natural capital). In this context economy should be interpreted as an element which encompasses manufactured "capital" accumulated to the economy. It consists of products and capital goods that are used to increase wealth and, in essence, rises out of the need to use scarce natural resources and labor more productively and efficiently.[16]

The time span covered in the study begins from the ancient times when rudiments of modern resource economic thinking were documented in early agricultural societies, and ends when the validity of the Faustmann model was fully established in modern resource economics. Progression towards forest and natural resource economic thinking in line with modern capital and investment theory is not expected to be smooth or linear over time. Political ideologies and socio-economic forces have shown great variance through history, and thus also the developmental paths in forest and natural resource economic thinking have been subject to various stages and transitional periods. Shifts from one mode of thinking to another have often been slow and sometimes almost imperceptible. In a similar way, the political, economic and social milieu and intellectual atmosphere have not been

[16] Alfred Marshall (1907, 135) gives the classical economic definition of "land" as a production factor: "By land is meant the material and forces which nature gives freely for man's aid in land and water, in air, light and heat."

universal or parallel across countries, which opens interesting opportunities for comparative analysis between those realms that are the focus of this study, England and Germany.[17]

The emphasis in the study is on those intellectual currents and transitional periods that have molded European societies and their political and economic structures, and thus may have had an important impact on the early progress of modern forest and natural resource economic thought. Drawing on earlier literature, the historical phenomena that may have had such an impact are

i) the treatment of land as a distinct natural resource;
ii) the moral, ecclesiastical and legal strictures against usury and their manifold implications in societies;
iii) the gradual shift from simple to compound interest calculations in early modern Europe;
iv) the emergence of modern capital markets, especially in Holland and England;
v) the quest for state formation, stability and domestic resource control in pre-industrial Germany (*Kameralismus*) and beyond; and
vi) the rise of physiocratic doctrine and the prelude of economic liberalism.

One should not interpret these as isolated events or periods but as potentially important and overlapping phenomena in the long intellectual process that prepared way and eventually led to the emergence of modern forest and natural resource economics. Figure 2 places these phenomena on a timeline that covers the core time period examined in this thesis, i.e. from the High Middle Ages to the rise of neoclassical economics. Although it is a stylized presentation, Figure 2 provides a temporal perspective for examining and understanding the emergence and early development of forest economic thought in conjunction with some larger social and economic undercurrents in western societies.

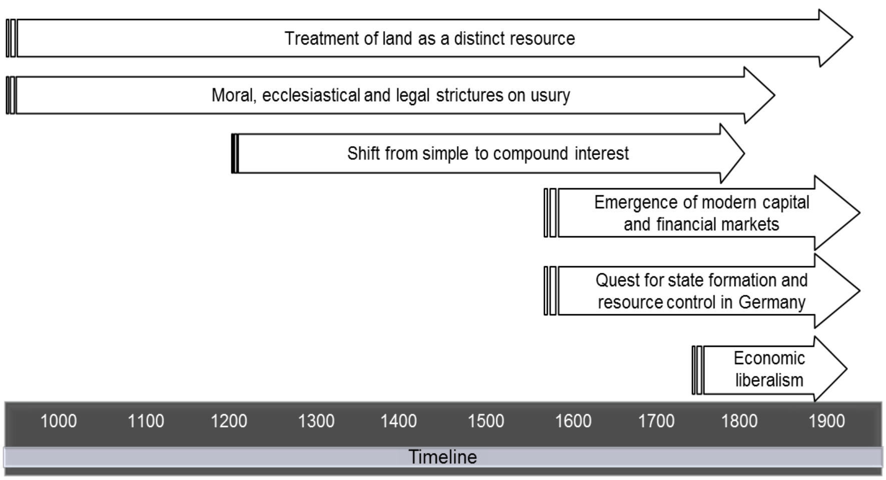


**Figure 2**. Historical phenomena influencing the development of forest and natural resource economic thinking.

[17] Prior to the unification in 1871, Germany consisted of a rather heterodox group of territorial states, also with regard to their political-economic environments and natural and other resources. In this thesis, 'Germany' is sometimes used collectively for brevity.

*Methods*

History is socially constructed, embodying interpretative strategies that are either explicit or implicit in how historians of economic thought pursue their works (Samuels et al. 2003). This has given rise to a variety of research methods in the field. The variety stems in part from the fact that historians of economic thought have different interests and thus different ideas about what types of historical phenomena are most intriguing and what are their plausible connections with more general political, social and economic developments. Different research styles and methods in the history of economic thought are presented and discussed e.g. in Samuels (1983), Medema and Samuels (2001), Biddle (2003), Samuels et al. (2003), Marcuzzo (2008) and Sandmo (2011).

Marcuzzo (2008) identifies four broad methods in the history of economic thought: i) textual exegesis; ii) rational reconstructions; iii) contextual analysis; and iv) historical narrative. *Textual exegesis* is a search into the meaning of a text. It accords its practitioners the right to establish the demarcation criterion for deciding the scientific character of given texts and consists of reviewing them in the light of the interpreter's contemporary economic knowledge. A coherent application of the method requires that the practitioner is first able to reconstruct the "general position" of the theoretical core of an author's work in a manner compatible with contemporary economic theory (Stigler 1965; Emmett 2003, 525; Marcuzzo 2008). However, a major problem in this notion lies in the implicit assumption that the interpreter already knows the author's general position before he or she begins to interpret the text. This gives rise to a dilemma called "hermeneutical circle": understanding any portion of the text requires knowledge of all the text; understanding all the text requires knowledge of every portion of the text (Emmett 2003).

Several ways to work with the dilemma has been suggested. Stigler (1965) proposes an approach that is derived from statistical analysis: in order to increase confidence in a particular interpretation of a text (general position of the author), one increases the amount of author's work taken into consideration. The problem is, of course, that this is not always possible. Another problem is that authors may not have been consistent in their ideas or theories: in some texts they may make remarkable contributions, in others they make mistakes or hold beliefs that are later proven false. Thus, increasing the source material may lead to situations in which the interpreter is likely to find more than one plausible way to reconstruct the past from its archives (Klaes 2003).

Another way to attempt to solve the dilemma is to adopt the view that the meaning of a text is determined not by the individual interpreter but by the scientific community (of economists), as they read and re-read the text over time. So the modern interpreter enters the hermeneutic circle as a professional (economist) with the profession's pre-understanding of the scientific meaning of the author's work in hand (Emmett 2003). However, the notion of the profession as the final arbiter of meaning may be problematic because it gives hermeneutic authority to one specific interpretive community (economists) over others that may be better skilled to interpret relevant (noneconomic) texts (Emmett 2003). Also, if the author and his text are new to the community or the community consists of various schools, pre-understanding on author's general position may not exist or it may not be characterized by a high degree of consensus. In all, the discussion of various aspects of textual exegesis demonstrates that many of the debates in the history of economics and economic thought arise from differences over the exegetical interpretive guidelines that one should follow in interpreting a particular text or texts (Biddle 2003).

*Rational reconstructions* refers to a method in which the ideas and arguments of past authors are reconstructed in a way that enables the interpreter to identify its relation to modern economic thought. The method can be used to support existing economic theory (present-day theory is appointed the judge of the past), but can also be practiced as a search into the past for alternatives, whereby it can challenge current theory. Marcuzzo (2008) denotes the former as "quest for ascendancy" (*Whig history*) whereas the latter is "quest for an alternative". Broadly speaking, the Whig history refers to the tendency to view history as a steady and rational progression from past errors to present truths.

Emmett (2003) argues that, as interpretive exercises, rational reconstructions differ from the construction of general positions in textual exegesis in four important ways. First, rational reconstruction deals with a subset of a past author's work. A narrower focus prevents abstractions that move too far away from the text under consideration. Second, the author's work is translated to modern theoretical framework which implies that mathematical modelling techniques and theoretical concepts unknown to the original author may appear in the rational reconstruction. Thirdly, since the focus is narrower than in attempts to search for past author's "general position", multiple rational reconstructions of an author's work may be possible. Finally, because rational reconstructions focus on particular parts of authors' work, they represent "little snapshots into the past". Thus they are as separate insights and discoveries less likely to be used as an indicator of the degree of scientific progress from the past to the present.

Some historians of economic thought have abandoned the attempt to assess the past in terms of the present (i.e. treating past writings as if they were written now) and opted instead for what has been called *historical reconstruction*. It focuses on reconstructing the meaning of texts at specific moments in the past and on text's relation to its own social, political, cultural and intellectual contexts. Piecing together the fragments of past and reconstructing a picture that encompasses important insights and discoveries in the midst of their own familiar surroundings enables to draw on continuance of economic ideas and to explore their motivating forces (cf. Marcuzzo 2008).

Besides published works, historical reconstruction involves perusal of biographies, manuscripts, letters and other archival sources. This extends the scope of inquiry but at the same makes it more complex because it requires that ideas and their evolution are examined as part of larger political, economic and societal development. This has given rise to questions how related materials, for example, correspondence, stand *vis-à-vis* purely scientific work (published or unpublished), and what is the importance of exploring archives rather than relying on published material alone (e.g. Biddle 2003; Marcuzzo 2008).

Marcuzzo (2008) makes a further distinction between two types of historical reconstruction: *contextual analysis* and *historical narrative*. The first refers to the general method of historical construction that involves the use of all such material which may provide clues to facts, individual and shared concerns, circumstances and motives, and thus help to place ideas and their evolution in time and context. This may lead one to ask questions which would not probably not have been asked without reconstructing such a larger historical setting. *Historical narrative* refers to a specific orientation in which the historical reconstruction has been directed towards lesser-known figures in the history of economic thought in order to answer to the need to examine the broader picture by searching for less theory-laden investigations, connecting intellectual circles, and linking characters and events. However, historical narrative is usually applied when one seeks to gain deeper understanding *why* certain individuals wrote and examined phenomena as they did. In comparison to contextual analysis, it deals more with aspects of subjective consciousness and intentions of the past actors. In many ways, it conforms to writing narrative micro-histories of everyday experiences of ordinary people, lesser-known figures, events or phenomena in the past.

In all, the classification of research styles and methods in the history of economic thought does not permit the drawing of any sharp distinctions between different styles; approaches are rather distinguished by the emphasis placed on different aspects. Although different methods are in some respects overlapping, each method has its locus in the field. Pure rational reconstruction, for example, may provide important information in cases when the focus is confined to certain theoretical constructions in the past, but in other instances the same method may miss the benefit of a rich background of ideas and past debates and thereby lead to fragmental or narrow interpretations in the history of economics or economic thought.[18]

The present thesis includes five separate studies which examine the development of forest and natural resource economic thought from somewhat different angles. Due to differences in scope and emphasis, the studies have distinct theoretical and historical relevance and implications to the overall objective of the thesis. Thus also the research methods differ across the studies.

Studies **I–III** and the summary section apply both rational and historical reconstruction because they not only trace new insights and ideas on the economic aspects of forestry and translate them into modern frameworks, but also aim to connect these constructs and events to broader intellectual movements and socio-economic developments in England and German territorial states. Study **IV** applies the rational reconstructions to translate Faustmann's newly discovered article on the economics of forestry into modern theoretical framework. Study **V** applies the same method to evaluate one particular group of texts which allegedly offer alternative models for analyzing optimal forest rotation in sustained yield forestry.

*Research process and sources*

The research proceeds mostly backwards in time. It begins with an examination of the articles on forestry that Faustmann published before and after his celebrated contribution in 1849 (Faustmann 1849b). After examining possible new leads of the origins of his reasoning in these articles, the study moves on to scrutinize the writings of such scholars who in the classical German forestry literature have been regarded as pioneers of modern forest economic thought. Outstanding examples of such figures are Georg Ludwig Hartig, Heinrich von Cotta, Gottlob König, Johann Christian Hundeshagen, Friedrich Leopold Wilhelm Pfeil and Carl Justus Heyer. After going through their contributions in the decades from the 1790s, and after following the new clues that this investigation may reveal, the research delves further back in time, to the early stages of "scientific forestry" in German

[18] Similar methodological issues have been discussed in the research of the history of science; in particular relating to differences between genres of *absolutist* versus *relativist* history, or using alternative terminology, *internal* versus *external* history (e.g. Blaug 1985; Emmett 2003; Waterman 2003). Broadly speaking, studies that focus on a text's relation to its own context are considered to be external, relativist or social history, while those that concentrate on the meaning that someone gave a particular text at some historical point are absolutist, internal or intellectual history. In many cases the above distinction is not very clear, as intellectual history often involves some degree of attention to the aspects of social history and vice versa (e.g. Waterman 2003). In general terms, however, a relativist approach is likely to be used for more distant periods, while an absolutist approach is adopted for a more recent period.

territorial states. The focus is on those pioneering treatises on forestry (and hunting and mining) that were published in the mid-eighteenth century and may contain traces of modern forest economic thinking. Seminal compilations on the history of German forestry (e.g. Bernhardt 1872–1875; Schwappach 1888; Hasel 1985) make it possible to extend the inquiry from the eighteenth century to the late medieval period (c. 1300–1500), though this endeavor is characterized by a substantial decrease in material.

Similar backward-looking approach is applied to the early English literature on forestry, forests and woods, which material, however, is far more scant.

When no more novel revelations or clues of modern forest economic reasoning could not be found in source materials (consisting of books, published articles and biographical material), the study turns to examine parallels in more general natural resource economic thinking, the focus being at agriculture and mining. In German states, the starting points are the seminal works of Albrecht Thaer (1798–1804; 1809–1812) and his most famous student Johann Heinrich von Thünen (1826; 1850; 1863), often considered the pioneers of modern German agriculture and agricultural economics. In Britain of similar status works are the regional surveys of agriculture which were carried out by, for example, Arthur Young (1768; 1770; 1771) and his great rival William Marshall (1787; 1808). Agricultural surveys have long traditions in Britain but those that were made in the late eighteenth and early nineteenth centuries were specifically aimed to give a basis for agricultural improvements and for determining what new lines of agriculture were profitable. From these pioneering efforts of modern farm management, the research once again moves further back in time to the early modern English agricultural literature in the seventeenth and sixteenth-centuries, including relevant compilations.

When connecting the development of forest and natural resource economic literature to the evolution of larger spheres of economic thinking, appropriate starting points are of the works of the early political economists at the turn of the eighteenth century, particularly those of Adam Smith (1776) and David Ricardo (1817). Both showed keen interest in questions of land use and valuation. From their classical works the examination again moves back in time to the physiocrats and other proto-classical figures in economic thinking, and then to the proponents of mercantilism and cameralism in the eighteenth-century England and Germany, respectively. Thereafter it enters the currents of the political-economic debates in the seventeenth century, which saw the formulation of relatively modern economic argumentation in England. The concurrent emphasis in German-speaking Europe was significantly more on theories and practices of state formation and effective administration. After entering the late medieval period, the focus turns more on those philosophical and moral questions that dominated discussion and practices related to interest taking, compound interest and land and other real property valuation.

Finally, the analysis is extended to cover the period from Faustmann to the triumph of modern (neoclassical) forest resource economics. Two issues in this examination are of particular interest: first, the rationale behind the persistent reluctance of relying on the standard Faustmann model in practical forest management, and second, possible intellectual connections and similarities between the emergence of modern forest resource economics and the early phases of more general neoclassical capital and investment theory.

# 3 EARLY COMMERCIAL ARITHMETIC AND LAND VALUATION

The main purpose of this section is to provide a broader historical background against which the emergence and early development of forest and natural resource economic thought should be understood and evaluated. It is shown that although commercial arithmetic with interest payments, compound interest, present and future values, as well as relatively sophisticated land and other property valuation techniques have been around for centuries, it took quite long until they were applied in a coherent manner to forestland and standing timber stocks. The section also elucidates why land and its biological products, including forests, have throughout centuries been regarded as a distinct form of capital and why land and other forms of natural capital still tend to have a special role in economic theory and analysis.

## 3.1 Development of commercial arithmetic

Earliest extant evidence of loan contracts with interest payments are the clay tablets from the period 1800–1600 BCE in southern Mesopotamia. These ancient contracts, written in cuneiform, so-called wedge-writing, stipulate that a loan will be repaid at harvest time with interest (Kopf 1926; Neugebauer 1951; Parker 1968; Lewin 1970; Homer and Sylla 1996; Hudson 2000a;b; van de Mieroop 2005).

Although the Babylonian mathematics was surprisingly sophisticated and allowed calculation of long-term values, most loans were for short-term because they were based on agricultural cycles: interest was due at the time of harvest, not on annual basis (van de Mieroop 2005). Thus the concept of compound interest was not important. There are some indications, however, that the idea of compound interest did exist, and that the defaulted interest could itself be subject to interest (van de Mieroop 2005). According to Goetzmann and Rouwenhorst (2005a), the Babylonian mathematicians typically used linear interpolations to approximate such nonlinear phenomena as the motion of the planets and compound interest.

The early orient civilizations wielded great influence on the classical Greeks. Despite Aristotle’s conceptions that money is intended to be used purely in exchange, not to increase at interest, and therefore it is unjust to make a gain out of money itself, also the Greek scholars applied their mathematical skills to the problems of simple and compound interest (Munro 2003). This tradition was transmitted to the Romans who had knowledge of arithmetic, algebra and the use of interest.

Although restrictions on interest payments somewhat varied in time and space during the core period of the Roman rule (c. 300 BCE–500 CE), generally speaking the Roman law prohibited lending money for a specified rate of interest between Roman citizens (e.g. Heichelheim 1970, 18–19). However, moderate interest rates were accepted under certain conditions (Munro 2008). Equity investments were one item that received special treatment: business partners could agree of compensation of actual damage such as fire or storm (*damnum emergens*), delay in payment of the principal (*poena detentori*) and lost profit (*lucrum cessans*). The last category may be viewed as lender’s opportunity cost since it represented foregone potential gains from an alternative licit investment in commerce or industry. These ancient guidelines and practices would be important for commercial and financial activities for centuries, because of the great influence that the Roman law, *corpus iuris civilis*, had on medieval and hence on modern legal systems (e.g. Stein 1999).[19]

With the decline of the Roman Empire in the fifth century much of the banking and monetary economy that the Romans had set up almost disappeared and the western Europe entered upon an 'economy of goods' (Kopf 1926). Since there was little manufacture or extractive effort during the early Middle Ages (about 500–1000 CE), there also was very little use for money as an adjunct to productive process. When money was lent, it was typically used for personal (consumptive) purposes, not for productive investments.

Because of the turbulent times and the lack of intrinsic security that would be used to back ordinary loans for consumption, interest rates tended to be high and oppressive. These practices were in contrast to the views that had been adopted and instigated by the early Christian Church. Payments beyond the principal sum that had been borrowed for consumption were found to be immoral, usurious, because money was considered 'barren' in a sense that one piece of coin cannot beget another piece of coin. Moreover, such compensations tended to exploit the poor and violate the manifested virtue of charity.[20]

### *Italian masters of present value*

The revival of gold as a medium of exchange and the development of manufacture and trade during and after the Crusades (1096–1272) led to gradual resurgence of commercial and financial activities. This progress was most apparent in the Italian city states, which in the twelfth century emerged as the centres of financial and commercial development in Europe.

Although the progressive Italian city states (e.g. Pisa, Genoa, Venice, Amalfi) were locked in intense trade and other rivalry, not only with each other but also with the Byzantium and the Muslim countries, Italian scholars were able to travel and receive instruction in such places as Egypt, Syria and Byzantium. Through their education, contacts and learned disputations with prominent scientists throughout the Mediterranean world, they became superior creative mathematicians (Sigler 2003).

An important early figure in the dissemination of advanced mathematical knowledge and technique to Europe was the Italian reckoning master Leonardo Pisano (c. 1175–1250), also known by the name of Fibonacci. His encyclopedic work *Liber abaci* (*Book of Calculation*), appeared first in 1202, introduced a new and revolutionary way to do arithmetic by incorporating the Hindu numeral system and its written procedures of calculation (algebra). Before, calculations had been done with Roman numerals (and other similar systems of writing numbers) and the abacus. Knowledge of the Hindu numerals began to reach Europe in the second half of the tenth century through the Arabs by the way of Spain, but their usage was still not a general practice at Pisano's time (Sigler 2003; Katz and Parshall 2014).

*Liber abaci* treated much of the known mathematics of the thirteenth century on arithmetic, algebra and problem solving. Moreover, it included a wealth of applications to all kinds of situations in business, trade and banking. Both simple and compound interest

---

[19] *Damnum emergens* was also called as *interesse*. The word originates from the Roman law regarding *quod interest*, 'that which is the difference' which applies to the payment that a delinquent party to a contract is required to pay to the damaged party (Noonan 1957, 105–106; Munro 2008).

[20] Term 'usury' derives from Latin *usura*, payment of the use of money.

were applied, and in some cases also correct future and present values were derived (Sigler 2003, 627–628; Goetzmann and Rouwenhorst 2005a). For these contributions *Liber abaci* has been regarded as the first modern (European) book on commercial arithmetic (Poitras 2000, 26).[21]

Later in the medieval period similar type of work was carried on and augmented by other competent Italian mathematicians and reckoning masters, for example Jordanus de Nemore (c. 1236), Dardi (1344), Luca Pacioli (1494), Girolamo Cardano (1545) and Niccolo Fontana, also known as Tartaglia (1556). Like Pisano, they were able to build on the earlier contributions of Greek, Arabian and Indian mathematicians who had mastered compound interest and present value calculations.

The aforementioned brief account demonstrates that the basic technique for modern commercial and financial calculations was available centuries prior to Richards (1730), Faustmann (1849b) and other early German 'forest economists' made their celebrated contributions to forest and capital valuation. However, the social and moral restrictions against using this technique in everyday situations remained extant, as described next.

### *Ancient and scholastic prohibitions on usury*

Just when the early commercial revolution reached its apogee during the thirteenth century, a religious and moral campaign against usury was vigorously renewed. The medieval scholastic theologians (e.g. Albertus Magnus and his most famous student Thomas Aquinas, 1225–1274), who had considerable influence on contemporary moral and religious sentiments, subscribed to the classical Aristotelian view that money is barren or unable to produce wealth: 'the birth of money from money is unnatural' (Viner 1978; Langholm 1984; Munro 2008). In light of this view, any interest payment in lending money would be categorized 'theft of property' which was of course a sin.[22]

The scholastic logic was based on a perception that there are fungible or non-fungible goods. Money and similar fungibles, such as grain and wine, were consumed by use and hence cannot be returned; instead they were to be replaced with identical objects or objects with identical value. Since interest payment on lent money represented an additional component in exchange, it was found to be against the commutative justice, equality of exchange. The non-fungible goods – like land, house and livestock – could be loaned or leased and returned in an identical state after use, which practice gave allowance to various annual compensations for their use (Viner 1978; Munro 2003). This distinction between different kinds of goods proved to be influential for social and moral attitudes well beyond the medieval period. Moreover, it greatly contributed to the development in which land and other real property classified as 'fruitful' were appreciated by the annual income stream they generated.[23]

---

[21] Pisano was trained in Arabic mathematical methods in the Pisan colony of Bugia in North Africa, today's Algeria. He then travelled extensively in the Mediterranean and upon return to Italy wrote the book *Liber abaci* (Watt 1972, 43; Goetzmann and Rouwenhorst 2005a).

[22] Another interpretation against usury was related to the time value of money. Some scholastics prior to and after Thomas Aquinas maintained that to charge a higher price on sales for future payment than for cash sales was to 'sell time'. Since 'time' was a free gift of God to all, a common good, it was usurious to make a charge (Viner 1978; Munro 2011).

[23] The distinction between different goods can be taken to have reflected the conditions in pre-urban societies where loans were typically made in agricultural products, such as seeds of grains and fruits and live animals. What was loaned, had the power of regeneration, and interest was a sharing of the result. Inorganic materials (e.g.

The church councils in the fourth and eight centuries had determined the charging of interest as immoral, but the denunciations had remained somewhat vague in a sense that only clerics were positively forbidden to engage in the practice. The ecclesiastic strictures became much more comprehensive in the period of most scholastic influence, i.e. from the twelfth to the fourteenth centuries, when three separate church councils condemned anyone who charged interest, regardless of the amount (Munro 2003).

The increasingly critical attitude towards interest charging practices was stipulated not only in the medieval Catholic Church law (cannon law) but also in civil laws throughout Europe. In England, the first enactment against usury was given in 1197 by Richard I, forbidding any recompense on money lent. Similarly, King Philip IV (r. 1285–1314) of France and his successor ordered royal bans against usury.

Although the scholastic movement enforced the traditional ban on usury, the Roman practice was effective in the sense that it was not forbidden to earn interest if the investor or lender was actually taking some risk, suffered some loss or passed up some opportunity by extending a loan. However, the exceptions that permitted to receive some payment beyond the principal were carefully defined. A major requirement was that the actual damage or delay in repayment incurred *after* having made the loan, i.e. excess payments based on ‘expected’ losses were not allowed. Also predetermined and fixed opportunity costs (*lucrum cessans*) were mostly rejected by the scholastics as they followed the reasoning that money could not be ‘fruitful’ in itself; it was instead the industry or enterprise of the lender which uniquely derived the gains (Munro 2003).

The practical effects of medieval usury regulation have remained somewhat controversial, mostly due to lack of extensive empirical data, but the consensus view is that money lenders, merchants and businessmen were able to evade the ecclesiastic orders and legal codes by designing transactions in a fashion that was consistent with the letter of the usury restrictions. A widely used method was the ‘triple contract’; a relatively sophisticated financial structure involving loan and insurance contracts between partners. Foreign exchange transactions were another means to circumvent usury restrictions: the payment of interest was hidden in the exchange rate which was typically quoted at a premium (de Roover 1944). Lenders also employed financial instruments where the rate of interest was hidden behind supplementary charges or concessions to avoid quoting a figure that would invite prosecution (Kerridge 1953, 22).[24]

*Toward more open interest charging*

The increase in commercial activities, especially from the late thirteenth century, and the growing need of capital in private and public ventures led to a situation where definitions of usury gradually became more diverse and subject to increasing number of exceptions. Perhaps the most important impetus to a more pragmatic general position was the growing awareness among secular and ecclesiastical officers that the lending of money had become increasingly important to economic activity and banning it would have had disastrous

---

metals, coinage) did not have powers of reproduction and any interest paid in them must originate from some other source or process – their only function was to facilitate exchange. For details, see e.g. Heichelheim (1958).

[24] The ‘triple contract’ involved a conventional Roman partnership or *societas* agreement between lender and borrower; an insurance contract in which the borrower guaranteed to the lender there will be no loss of capital; and yet another insurance contract with the borrower agreeing to pay the lender a fixed rate of return in exchange for the lender agreeing to forego a share in any eventual profit (e.g. Poitras 2000, 38).

consequences. It has been contended that despite the scholastic prohibitions and legal restrictions, no medieval European government was able to function without borrowing because its powers to tax and exact various payments were typically limited and it was often engaged in costly wars (Davis 1960; Jones 1997; Munro 2003).

Already in the mid-twelfth century, the Italian city states had established various sophisticated credit systems in which they issued voluntary and forced loans to be reimbursed (with interest payments) from commercial tax revenues. The public loans were usually for short terms, often re-payable as annuities for a term of years, but in some cases the financial difficulties of the local governments became so ample that all redemptions of principal ceased and the loans actually became perpetual liabilities (Munro 2003). During the next century similar practice in public finance spread to other parts of Western Europe.

An increasing size and sophistication of mercantile and banking activities – first in the Italian city states and then gradually also in other European trading cities – put more emphasis on proficiency in commercial arithmetic. Italian reckoning schools had offered education on sophisticated arithmetic since the twelfth century, in some cases also to scholars from other countries, but from the mid-fifteenth century similar institutions were established throughout Western Europe (Swetz 1987). The quest for enhanced education was also spurred by the revival of science and new modes of thinking, the Renaissance. Since the reckoning schools were aimed at merchants and usually operated outside the realm of the Church and humanist dominated universities, the emphasis in instruction was on practical problems of commercial and financial life. This resulted in curricula that took influence from other subjects such as accounting, engineering and actuarial science.[25]

The unravelling of the scholastic prohibitions on usury accelerated in the sixteenth century. An important factor in the transition toward more tolerant attitudes concerning interest charging was the Reformation which led to a breakdown of religious unity and decline of the authoritativeness of theological pronouncements on economic matters. Another contributing factor was the invention of the printing press (in 1450 by Gutenberg) which facilitated the dissemination of knowledge and information.

With the rapid spread of arithmetical books and instruction and the gradual acceptance of taking moderate interest charges, the period of hidden information involving the computation of interest started to come to an end. Soon reckoning masters throughout Europe wrote and published texts that included business illustrations and commercial rules so that readers were able to find the calculations of buying and selling, profit and loss, business partnership, and even of the taking of interest in their native language (Poitras 2000). Many of these writers were themselves involved in trade or acted as mathematical advisors for businessmen, large banking houses or kings, all of whom were dependent on the proper functioning of local or international financial markets.

The change in social and moral attitudes was most pronounced in the Lowlands, England and northern German states. In the beginning of the 1540s, the Estates General of the Habsburg Low Countries (subsequently unified as the Habsburg Netherlands) legalized interest payments up to twelve percent per annum on all debts and commercial bills, thus permitting open discounting (van der Wee 1963). The move attracted more capital to the country and contributed to a situation where opportunities for raising capital for commercial or industrial venture were greater in the Netherlands than anywhere else at the

[25] Modern business schools have their historical roots in the Renaissance reckoning schools (Poitras 2000, 10).

time (’t Hart et al. 1997). The Dutch took the lead in international trade, and Amsterdam grew into the commercial and financial capital of the world.[26]

In England, a major modification in the laws governing usury was made after Henry VIII had broken with Rome. The prohibition on interest charges was removed in 1545 so that only exceptionally high interest rates were condemned as usury; maximum permissible rate applied in all transactions was set to ten percent (Kerridge 1953, 22). Under Catholic Queen Mary, the taking of interest was once more outlawed in 1552 but the maximum rate of ten percent was reinstituted in 1571. This rate was lowered in three consecutive steps: in 1624 to eight percent and in 1651 to six percent. It remained at this level until the year 1714 when it was fixed at five percent, a rate that was effective until the abolishment of the usury laws in 1854 (Kopf 1926).

After 1640, and especially after 1660 the continuous literature on usury ceased in England. Reflecting the fact that the economic aspect of the question superseded the moral aspect, the word ’usury’ nearly disappeared from financial terminology and was replaced by ’interest’ (Letwin 1963, 81–82; Appleby 1978, 66–70). This change opened a door for the development of remarkably modern financial markets in the country. As explained later, it also prompted the exposition of first modern forest economic insights.

### *The concept of interest in early forestry*

Considering that the roots of classical forestry are predominantly German, it is of special interest to explore the early use of the concept ‘interest’ (*Zins*) in German forestry-related texts. Although an in-depth examination of this issue is a formidable task and thus out of scope of this thesis, extensive compilations on the history of German forestry (e.g. Bernhardt 1872–1875; Schwappach 1888; Endres 1911; 1922; Hasel 1985) provide some useful lead to the subject.

According to Endres (1911, 183; 1922, 161, 464) the term *Verzinsung* (payment of interest) was mentioned in 1577 in a forest enactment of the principality of Pfalz-Neuburg (Bavaria). This statute, amended in 1690, contains a section which rules that if usufruct or leasehold forests (*Lehen- und Zinswaldungen*) were overharvested by the holder or tenant, the attributable loss was to be compensated to the landowner. The offender had to pay an interest on half of the timber income that the forest had yielded during the last six years, and in certain cases this obligation was extended to infinity.[27]

Even earlier references to interest payments, either in money or commodities, are plausible in German forestry-related texts considering that commerce was active at the late medieval period (c. 1301–1500) and sophisticated credit systems grew increasingly important in many parts of the country. The first German book of arithmetic (*Rechenbuch*) was compiled in 1482 by Ulrich Wagner and soon others followed (see e.g. Franke 2001, 166–206). The most famous German reckoning books appearing in the Renaissance period, that is, the era immediately following the Middle Ages, were the works by Saxon court mathematician Adam Ries (1522) and Peter Apian (1527). Both books went for several editions and showed how interest calculations could be applied to commercial situations.

[26] For a detailed description how the emphasis in commercial and financial development shifted from the Mediterranean to northwestern Europe, see for example Braudel (1972; 1981–1984).

[27] For the original section, see *Deß Fürstenthumbs Neuburg, Erneuerte Forst und Holtz-Ordnung* (1690).

On the other hand, one may expect that the application of interest calculations to forests was likely to receive but little attention until the late medieval period because woodland, pasture and other less productive lands (compared to arable) were typically under communal, manorial or royal ownership. Their main function was to supply wood for local building and heating as well as to provide opportunities for manorial and court chase. Landlords could have rights to parts of the woodland which they could let for an annual payment, but other parts were free for all in the community.

With the sharp rise in population in the high medieval period, many manorial and territorial lords sought to seize the right to use the common lands too. These attempts gave rise to various local (written or oral) agreements of the rights of ownership in common lands and associated compensations for using timber and other rights in the woods. As will be described later, it was these payments (e.g. *rentes*) for the right to use agricultural land and other 'fruitful' property that would provide a basis for modern forest and capital valuation.[28]

### 3.2 From simple to compound interest

The concept of compound interest has been recognized at least four thousand years, but it was simple interest that was usually allowed and used in commercial calculations and financial transactions in the ancient orient civilizations. The Greeks and Romans subscribed to this tradition, though there is evidence indicating that also compound interest might have been used in some carefully defined business transactions (e.g. Divine 1959; Poitras 2000).

The dominance of simple interest as a market practice continued in the medieval and Renaissance commerce where the Roman style partnerships (*societas*) and bills of exchange (pledges of credit from responsible merchants) were perhaps the most common financial transactions. The failure to incorporate compound interest has been identified to be due to the usury restrictions and required simplicity of calculation in business agreements (Poitras 2000, 158). Since compound interest calculations were substantially laborious to perform without tables, they might have found most use (perhaps in various forms of rule-of-thumb) in those private equity capital contracts that involved very unequal investment durations and compensations for lost profit (*lucrum cessans*). Even then, payments of interest, especially on accumulated interest, had to be disguised in various types of seemingly legal or morally acceptable contracts to avoid potential civil and ecclesiastical penalties.

The Italian mathematicians, making substantial contributions from Pisano's time, had used compound interest to motivate the solution of equations with exponents, but in the early Renaissance texts of commercial arithmetic compound interest was commonly discarded. The first printed book on commercial arithmetic, *Treviso Arithmetic* (1478), by some anonymous reckoning master and published in Treviso, a town in the Venetian republic, is an example of this habit. The book provided a wide range of practical instructions and worked solutions for problems rising in medieval and Renaissance commerce, but even the most sophisticated calculations were based on basic arithmetical

[28] For an outline of the characteristics and development of the manorial and territorial land-use systems and related ownership and tenure rights in Central Europe and England, see e.g. Bernhardt (1872), Schwappach (1888), Gras (1925), van Bath (1963) and Overton (1998). For common woodland rights in medieval England and German states, respectively, see Birrell (1987) and Bernhardt (1872).

operations (e.g. multiplication, division). These operations satisfy the needs of simple interest calculations whereas understanding the logic of compound interest calculations requires knowledge of powers, roots and other more sophisticated elements of algebra. Many reckoning masters probably had this knowledge, but it was not wise to apply these skills openly, because charging interest and especially interest on interest still remained subject to moral strictures.[29]

In addition to texts intended purely for use by merchants, there were treatises that aimed to incorporate commercial arithmetic into a broader mathematical framework. Nicolas Chuquet's *Triparty en la Science des Nombres,* which first appeared in 1484, is a well-known example of this kind of scholarship. Chuquet was as a writing master (*escripvain*) in Lyons, one of the commercial centres of Europe at the time. Although *Triparty* did not contain compound interest solutions, it is important for its explicit recognition of compound interest in the sense that it pointed out that the conventional commercial calculation methods of the time (e.g. rule of three) reflected a dismissal of 'profit on profit' (Poitras 2000, 159).[30]

Also Luca Pacioli (1494) avoided the usury issue in his famous *Summa de arithmetica* which leaned heavily to Pisano's work, at the time known in manuscript only. However, *Summa* did contain the so-called "rule of 72", an ancient, quite accurate and convenient financial method to calculate the number of years required for a present sum of money to double at compound interest.[31]

## *The prelude of compound interest*

Although compound interest gained ground with scholarly authors in the sixteenth century, it still did not become prominent in everyday commercial situations. Widespread application of such calculations would have required more social and moral acceptance and the availability of sufficiently detailed tables that would facilitate the use of the method. Interest tables for commercial purposes had long been around, but such tables were usually treated as highly confidential. Besides being indispensable instruments for large banking and merchant houses at the time when there were few skilled calculators, their publication could have led to even more intensive moral and religious criticism against this type of business practices.[32]

Tables for simple and compound interest calculations were first printed in Lyons and Antwerp, the most important financial centres of the western Europe in the sixteenth

[29] Already Pisano (1202), whose works in arithmetic and algebra were copied until the late fifteenth century, had discussed compound interest questions and puzzles. However, he carefully avoided addressing loan values and instead focused on future value problems, an issue medieval philosophers were not as well acquainted with. He posed questions and examples of the future value of a unit of currency and investments and, most famously, how many rabbits would be the result of an original pair, assuming continuous rabbit compounding (Sigler 2003; Geisst 2013).

[30] 'Rule of three' involved three factors of which one was unknown and could be solved with basic arithmetical operations.

[31] According to the rule, an investment that increases at 8 percent a year, for instance, will double every nine years because 72 divided by 8 equals 9. This holds because the future-value factor is $(1.08)^9 \approx 2.0$ (see e.g. Alchian and Allen 1972, 181). The method provides useful approximations for the principal to double also with other interest rates.

[32] An early survived manuscript containing interest tables was prepared by a Florentine wool merchant and employee of the mighty Bardi banking house, Francesco Pegolotti, about 1340 but published only in 1766 (Evans 1936).

century. A Lyonnese reckonmaster Jean Trenchant (1558; 1566), who was probably mathematical advisor to the king's officers or to the banking houses in Lyons, published them in his *L'Arithmetique,* a treatise which is noteworthy also for presenting a good method of computing interest over a fraction of a year. Interestingly enough, when Trenchant worked in Lyons, the city hosted a sizable Italian community, members of which were actively involved in economic affairs (Poitras 2000, 125).

Trenchant provided tables for both future value and the future value of an annuity for up to six years, mostly at four percent per annum, but a few decades later the famous Flemish mathematician and engineer Simon Stevin (1582) went significantly beyond him in providing extensive tables for present value $(1+i)^{-T}$ and present value of annuities $[(1+i)^T - 1]/i(1+i)^T$ for $T \in \{1, 2, 3, \dots 30\}$ and $i \in \{1\%, 2\%, 3\%, \dots 16\%\}$ (Dijksterhuis 1955; Struik 1958). Stevin also demonstrated the relationship between present value and future value, for both single cash flows and for annuities.

In an appendix of his remarkable *Tafelen van Interest* (*Tables of Interest*) Stevin even went on to describe "a general rule for finding which is the most profitable of two or more conditions and by how much it is more profitable than the other". The rule was about finding the present value of each proposed condition in respect to a given rate of interest, the difference between these present values showing by how much one condition is better than the other. This is clearly the net present value criterion of choosing between alternative investments (Struik 1958; Parker 1968; Poitras 2000).[33]

Trenchant's and Stevin's initiative led several others to the publication of books on interest. Especially extensive this activity grew in Holland, where a rapid commercial and financial development prevailed and calvinism with its relatively tolerant attitude towards other religious groups and open appreciation of the business life had a dominating influence ('t Hart et al. 1997). This socio-economic environment may have had something to do with the fact that land was short in supply and nobility weak. Unlike in those European countries that were locked in feudal systems and adjuvant power structures, it was the commercial oligarchy that dominated the Dutch society (Kindleberger 1985, 159). Their major interest was to promote trade and active financial markets.

### *Transition in England*

After the turn of the seventeenth century, the number of books on interest computation with and without tables increased considerably and sophisticated commercial arithmetic tables became common also in other countries and languages. The first compound interest tables in the English language were by William Colson (1612) whose book contained tables of $(1+i)^T$ at ten percent per annum, for $T = 1$ to 21 years, with some elementary examples of their use.

Richard Witt (1613) was the first to produce a comprehensive English textbook on the subject, with an extensive range of tables and many worked examples that readers could apply to their own problems (Lewin 1970, 130; 1981). The book, containing future values up to 30 years and also less than annual compounding frequencies, can be taken to imply that by 1613 it was widely accepted in England that compound interest should be allowed

---

[33] Simon Stevin (1548–1620) was born in Bruges (Flanders) and studied in the University of Leiden. He made significant contributions to trigonometry, mechanics, architecture, fortification and navigation. He wrote almost all of his works in Dutch.

in ordinary business and legal transactions and that the methods of carrying out the arithmetic were clearly understood. It also shows that the difference between simple and compound interest was fully appreciated (Lewin 1970, 128).[34]

An abundance of interest tables appeared in England during the next decades, partly as a result of the invention of logarithms (in 1614 by Napier) which facilitated their compilation. It is useful to note, however, that an important motivation of the early commercial books with simple and compound interest tables was to provide information on the valuation of various annuities and leases. A convenient feature in life and perpetual annuities (and leaseholds) was that, in contrast to term annuities, they did not involve repayment of the principal. Since there was no outstanding loan to be paid back, there could not be usury either.[35]

The most interesting aspect in annuities and leases concerns their valuation, which was based on the income streams these financial contracts were expected to yield. The value of a piece of agricultural property was commonly described in terms of the annual income that land produced in rents, rather than in terms of a single number indicating how much it would take to buy the land outright. This gave rise to valuation methods that were based on "years' purchase", a notion that developed into generic of present value.

To follow the intellectual path toward modern forest and capital valuation, let us next consider how annuities and their close variants *census* and *rentes* shaped early forms of land and property valuation.

### 3.3 Conversion of income into value: annuities, *census* and *rentes*

Similar to interest charging, the use of annuities can be traced back to orient civilizations about 2000 BCE. In Babylon, for example, there seems to have been a fairly wide-spread practice of granting a series of periodic payments secured by land or other property. Kopf (1926) suggests that these practices may have been adopted even before from the commercial codes of the Hindus and Chinese.

This ancient tradition was transmitted to the Roman legislation where the purchase and sale of annuities, both for life and for fixed terms, was widely prevalent. Annuities were commonly used for insurance and pension purposes: in return for a lump sum payment, the buyers or nominees received a fixed yearly payment for life or for a specified period of time. Another common purpose was to compensate those family members who were not directly entitled to inheritances in terms of family estates but were to receive a portion of the inheritance according to socially determined rules.

The acceptance of annuities in Roman law was carried forward into the medieval *census* (or *cens*) contracts. Monasteries in the eighteenth century were seeking ways to strengthen their status and finances, and for this end they developed contracts that would attract

[34] Many of the early English writers probably learned modern business practices and calculations from their counterparts in the Low Countries, particularly in Holland and its prosperous city of Amsterdam. At the end of the sixteenth century there also was a wave of skilled emigrants from southern Low Countries to Holland and England. Richard Witt, 'practitioner of mathematics' in London, may have been part of this emigration (Poitras 2000, 185–186).

[35] Also in modern financial accounting perpetuals are often distinguished from conventional loans. According to IFRS, perpetual subordinated bonds that are unlikely to be redeemed before expiration can be classified into equity capital, as opposed to liabilities.

bequests of land from the laity. In return for surrendering all property rights of the land to the monastery, the donor would receive an annual usufruct income (*redditus*) from the land donated for the rest of his life and sometimes for the lives of the heirs as well. The earliest medieval example of this kind of annuity contract involving land or other real property has been traced to a Carolingian Abbey in St. Gallen, in present-day Switzerland, about 700 CE (Munro 2003).[36]

The recurring annual income (annuity) in the early *census* contracts was usually deemed to be part of the 'fruits' of the property, for example the harvest (wheat, wine, olive oil etc.). However, from the twelfth century, after the gradual resurgence of commercial and financial activities, it was more commonly delivered in money, and thus the annual payments determined in the *census* contracts came to be known as *rentes*, reflecting an old French word of 'income'. From the French language, the term *rente* then made its way to other European languages, for example to English (*rent*), Italian (*rendita*), Dutch (*rente*) and Spanish (*renta, juro*).[37]

The medieval landed estates were often tied up with feudal conditions so that they could not be sold outright but means were found of doing practically the same thing (Munro 2003). Reflecting the need for flexibility in transactions, the early monastic *census* contracts evolved into other private contracts in which the usage right to a real estate was sold in return for annual compensation. Landlords seeking for capital funds to finance their private ventures or expenses soon realized they could also obtain credit from local monastic institutions by pledging the usage fees (*cens*) paid by their peasants instead of having to mortgage the land itself. From this feudal practice arouse the idea of selling the income flows of one's private property (land, buildings or other real estate) by constituting a *rente* on that property. In this convention, the right to a *rent* (annual income) from a certain piece of land became a right capable of transference.

Although several variants of *census* and *rente* contracts were offered in continental Europe during the Middle-Ages, from our point of view the most interesting ones are those that explicitly involved long-term fixed income as financial compensation for selling land or related tenure rights. In medieval Flanders, northern France's most important county, two specific forms of *census* were commonly used in private credit (Munro 2003). The older of the two (*bail à rente*) involved a sale of a real estate or some form of fixed property in return for a perpetual annual income. The other form (*rente à prix d'argent*) was a contract by which the property holder sold, for a specified lump sum of money, the right to receive a fixed annual income from his property or other real assets, while retaining the ownership of the immovable capital (Munro 2008). Obviously, both contract types called for technique that would appraise future income streams.[38]

---

[36] An usufruct is the right of temporary possession, use or enjoyment of the advantages of property belonging to another, so far as may be had without causing damage or prejudice to the property (Poitras 2000, 225).

[37] The word *rente* originates from the French and Latin verbs *render* and *reddere* respectively ('to give back' or 'return'), and from the latter's participle *redditus* (that which is 'given back' or 'returned'). In German language the term *Rente* is used more broadly than in English, as an income of any sort; *Grundrente* meaning the rent of land, and *Capitalrente* (like *Capitalzins*) the income usually in English called (according to conditions) either dividends or interest (Fetter 1926, 155; Skeat 2013).

[38] It was this form of private arrangements – widely diffused in northern France, Germany and the Low Countries from the thirteenth century – which subsequently became the basis also for long-term public credit in the same regions (Tracy 1985; Munro 2008). Local urban and territorial authorities began to sell *census* and *rente* contracts to raise public finances by undertaking an obligation to make (annual) payments from a public monopoly, tax receipts or lands. The arrangements were similar to those that many Italian city states had successfully applied from the 1150s.

Many scholastics regarded *census* and *rente* contracts as licit because they were classified as contracts of purchase and sale, i.e. they did not involve loans in a traditional sense. Moreover, like socially and morally acceptable annuities, they were typically designated for one life, usually extinguished on the death of the holder; or for perpetual lives, not in a strict sense 'perpetual' but often issued for two or three designated lives. When one life (or several lives) dropped out, the contracts on lives came subject to renewal, in which process a new life (lives) was often added. As a consequence, the contracts became hereditary and subject to revaluation at some indeterminate intervals.

The remaining taint of usury disappeared with the issue of fifteenth century papal bulls which defined that *census* or *rente* contracts were licit under three conditions: the contracts were tied to real estate or to other real ('fruitful') property; the annual return or annuity payment did not exceed ten percent of the capital sum; and the issuer (but not the purchaser) had an unrestricted right of redemption. The idea again was that since the principal was not to be repaid, no loan was involved and thus there could not be usury (Munro 2003).

To elucidate the intimate relation to modern forest and capital valuation, it is useful to note that it was an effort to value "annuities and leases on lives" and other dealings in connection with estates and tenures that induced John Richards (1730) to present calculations in line with the Faustmann formula. Moreover, it was the Danish actuary and applied mathematician Jørgen Pedersen Gram (1876), at the time working in a private insurance company and pondering questions related to the valuation of life annuities and assurances, who may have been the first to solve analytically the profit maximization problem that corresponds to the Faustmann formula (see Helles and Linddal 1997). In his celebrated discussion of the relation between capital and income also Irving Fisher (1906) explicitly referred to the long-standing practice of valuing terminable and perpetual annuities by the future income they are expected to yield (p. 202–226).

## 3.4 Land valuation practices in early modern England

The more tolerant attitude toward charging moderate interest rates and modification of the usury laws from 1545 led to a social and economic development where interest calculations became more widely accepted in England. Reflecting this institutional change, books that gave instructions and tables on valuing annuities and leases started to come out in profusion.

Although leases of land came in many varieties (annual tenancies, lifeleaseholds etc.)[39], the common feature in them was that future income streams were subject to appreciation or price setting not only upon purchase, but also upon renewals and reversions. In the last category, the right to use the land lapsed before the due time (for example because of the death of the tenant) and the property or tenure right was returned to the grantor of the lease. This brought out the question of the economic compensation (value) for the remaining part of the lease.

The first English language treatises with extensive tables for appraising the value of various leases and annuities were by Richard Witt (1613), Thomas Clay (1618; 1624), William Webster (1620; 1629) and William Purser (1634). Most of their tables were limited

[39] For details see e.g. Clay (1981).

for periods up to 31 or 33 years, corresponding to customary ‘three lives’ in annuities and leases. An exception to this practice were the valuation tables for freeholds, called also as ‘fee-simples’, which were estates of land that the Crown had given forever in the sense that the owner(s) had the right to own the property during their lifetime and typically had a say in determining who gets to own the property after their death, albeit the Crown retained the actual (legal) ownership.[40]

Witt, Clay, Webster and Purser did not provide any compound interest functions from which their table values could have been derived. Instead, all annuity and property lease prices were quoted in *years' purchase*, which was a generic determinant of present value in the British terminology. For example, given an interest rate of ten percent, a leasehold or annuity certain for 16 years implied 7.8 years’ purchase. To illustrate the equivalence to present value, let us denote years’ purchase by $y$ and interest rate by $i$. In the above case we obtain $y = \sum_{n=1}^{16} 1/(1+i)^n = \sum_{n=1}^{16} 1/(1+0.10)^n = 7.8$.[41]

In the case of freeholds and perpetual annuities, years’ purchase was the discount factor of an infinite stream of constant payouts, i.e. $y = \sum_{n=1}^{\infty} 1/(1+i)^n = 1/i$. Denoting annual land rent by $r$ and rental value of land by $V$ we can write $V = ry = r\sum_{n=1}^{\infty} 1/(1+i)^n = r/i$. The approach accords with modern capital-theoretic (Fisherian) reasoning that the value of capital (land) depends exclusively on the future income (rent) from it. A common procedure with perpetuals was to take an inverse of years’ purchase and translate the result to represent the assumed interest rate. In this convention, sixteen years’ purchase, for example, translated to an interest rate of 6.25 percent ($100 \times 1/16 \cong 6.25$). This holds since $1/y = i$.[42]

It is somewhat elusive who provided the first formal description of the present value of a perpetuity (e.g. Goetzmann and Rouwenhorst 2005b). The mathematics of infinite form of geometric progression, the geometric series, was examined by Euclid and other Greek scholars around 225 BCE. The idea recurred in various forms in medieval arithmetic texts but the general formula was perhaps not given until François Viète in 1593 (Poitras 2000, 154).

Before the above modern practices (employing compound interest) gained acceptance, years’ purchase was simply the price of the annuity (lease) divided by the annual annuity payment (rent). This valuation method was consistent with the ancient Roman market practice of quoting life annuity prices by multiplying the annual life income by the term to maturity (Hald 1990, 117; Poitras 2000, 188). A modern financial interpretation would be that in this convention years’ purchase was a multiple that could be used like a price-earnings ratio (P/E), which measures the current price against the most recent (or expected) earnings. For example, a lease value of £4 000 and an annual net income of £250 would imply that years’ purchase or P/E is 16 (Harrison 2001; 2004). Also this technique illustrates the intimate relation between rents and value.

An analogous method had been used in determining the sale-price of land in the mid-sixteenth century after Henry VIII had decided on the dissolution of ecclesiastic property.

[40] Under the manorial system, peasants farmed the arable land but owed rent, labour obligations and periodic taxes to the lord of the manor. However, through clearing the remaining scrub, meadow and woodland around the manor for use in agriculture, the peasants could obtain partial freedom from their manorial obligations, i.e. additional freehold land (Bailey 1989).

[41] To provide some historical perspective to the use of years’ purchase in economic nomenclature, the term appeared three hundred years later in Sir John Hicks’ classical exposition *Value and Capital* (1946, 188).

[42] As described by Heske (1938, 297), the yield value of farmland in pre-WWII Germany was usually taken as twenty-five times the sustained net yield derived from it, whereas the same factor was 18 in forestry. These multipliers (years’ purchases) imply (risk-adjusted) interest rates of four and 5.6 percent, respectively.

The task of auditing and selling the monastic lands on behalf of the Crown was given to the court of Augmentations, which in the 1540s almost invariably employed twenty years' purchase in this type of calculations (Habakkuk 1958; Thirsk 1967, 336–345; Scorgie 1996). Woods were separately valued. The convention was to use similar approach as with other lands or value them at a capital sum based on acreage or on the number of growing trees (Hammersley 1957; Thirsk 1967, 342–343).

Considering the extensive literature on valuing agricultural lands in early modern England, Richards' (1730) and Faustmann's (1849b) contributions in this area may actually lie in the fact that they extended similar principles to concern more complex natural resources which generate perpetual periodic series of net income at intervals of considerable time. To evaluate the validity of this proposition, let us turn to examine the discussion on the theoretical linkages between interest rates, land values and timber supply before and after the 'English Financial Revolution'. This remarkable period, spanning from about 1690 to 1720, seems to have been a landmark not only for the development of modern financial markets, but also for the emergence of modern forest and natural resource economic thought.

# 4 THE EMERGENCE OF MODERN FOREST ECONOMIC THOUGHT

## 4.1 Interest rate, land value and timber supply

Early English agricultural literature had treated such forestry related questions as "sale of wood and timber", "how to value timber" and "when to cut down timber", but from the point of view of controlling the planting and cutting processes (see e.g. Fitzherbert 1534; Mascall 1569; Tusser 1573; Plat 1594). Although numerous advanced handbooks for agricultural improvement appeared in the following decades (see Thirsk 1983), their contribution in matters of forestry was quite scarce in modern perspective. The popular work by Gervase Markham (1613), for example, drew upon German agricultural writer Conrad Heresbach (1577), who in turn had mostly followed ancient traditions as they were recorded by e.g. Pietro Crescenzi (1471) [for details, see Sharp (1975)].

In the mid-seventeenth century, on the eve of English Financial Revolution, British agricultural literature – exemplified by such prominent writers as Walter Blith (1649; 1652), Samuel Hartlib (1652), Ralph Austen (1653) and John Worlidge (1669) – continued to focus on instructions on how to grow and propagate different types of plants and to achieve agricultural improvements without articulating any modern forest economic insights.

The first practical treatises on forestry to be written by a private individual with the aim of stimulating the progress of forestry in England were the pamphlets by Arthur Standish (1611; 1613; 1615) [for details, see Linnard (1974); Sharp (1975)]. Although these works included calculations on the economic benefits of tree planting and different thinning regimes, simple and compound interest were absent. Another early practical treatise on forestry, most likely written by a surveyor of royal forests, Robert Chambers (1612), contained a brief discussion of the rents attainable from royal forests and promoted a view that forestry is not much interior to growing corn or hops. However, Chambers also failed to recognize the opportunity costs of forest capital, as his main argument was that young trees grow without further charge or labour whereas growing corn or hops involves continual charges (seeds, tillage, digging, delving etc.).[43]

Also the calculations on the comparative costs and long-term yields of timber, arable and cattle farming that appeared for the first time in the third edition of John Evelyn's famous *Sylva; or a Discourse of Forest-Trees* – published in 1679 and aimed at demonstrating the supposedly great advantages of planting and sowing oak, ash and chestnut trees – did not contain any references to investment calculations with compound interest. This may reflect the fact that *Sylva* (first published in 1664 without the aforementioned calculations) was a collaborative work, written at the request of the Commissioners of the Navy and undertaken by a number of fellows of the early Royal Society. Since many of them had a background in natural science, their primary interest was on biological and technical aspects of timber production, such as the best season to cut timber to avoid it from shrinking and warping (see e.g. Plot 1686). It was their compatriots engaged in the famous 'interest-rate-debate' who diverted from this intellectual pattern.

*Interest-rate-debate*

From the early seventeenth century economic writing began to flourish in England. Monetary and tax policy, international trade and national well-being were matters for increasing public debate and administrative promulgation. The famous interest-rate-debate, emerging around the mid-seventeenth century, may be regarded as one of the most visible contemporary intellectual reflections of the more general ambition to promote economic activity in England.

A major controversy in the discourse concerned the scope of government regulatory policy and the level of the maximum interest rate which in 1651 had been lowered to six percent. Many writers promoted the Dutch society as a model for England and asserted that the high English interest rate made lands sell cheap and that, being cheap, they were not improved. One of the primary advocates of the interest rate reduction, merchant and politician Sir Josiah Child (1668), concluded: "...where money is dear, land is cheap; and where money is cheap, land is dear". To support his case, Child claimed that if the rate of interest in England was reduced to the same level as in other countries, most notably in Holland, the nation would become more prosperous and lands would be valued at twenty years' purchase [implying an interest rate of five percent] rather than at the prevailing sixteen.

Child's comments and subsequent discussion may be taken as a further indication that the connection between interest rates and land values was well established at the time in England. However, there was ambiguity how rents were connected to a larger economic system encompassing factors of production, opportunity costs, profits and market equilibrium. In his famous *Treatise of Taxes and Contributions*, Sir William Petty (1662a,

[43] Only initials "R. C." appear on the title page. Fussell (2003) attributes the work to Robert Chambers but James (1996, 35) to Rocke Church (Rooke Churche), perhaps a *nom de plume*. The contents of the treatise suggests that the writer was an experienced land and timber surveyor.

42–49), polymath and political economist, made an effort to explain the “mysterious nature” of rents and “natural and true rent” and came very close to saying that real rent is a surplus (Letwin 1975). Later the surplus theory of rent, emerging from the inelasticity of land in supply and differences in land productivity, was to become an important element in the physiocratic doctrine and was elaborated in the Ricardian theory of land rent.[44]

Others, e.g. philosopher John Locke (1668), were against lowering the interest rate by law. In their mind this type of regulation would not increase land values because these were determined by quite other influences, in particular by the number of buyers and sellers and the “natural” rate of interest in the market. On the contrary, lowering the interest rate to four percent by a statute (a level suggested by some commentators) would discourage men from lending money and thereby affect negatively on the level of production and trade so that eventually landlords would not be able to get farmers to rent or purchasers to buy their land.

At the height of the debate, Thomas Culpeper Jr (1668) came to extend the discussion to concern forests. He proposed that Parliament should lower the legal interest rate because the prevailing rate of interest led to high interest payables which forced all indebted landowners to cut all timber from their estates:

> “However, Certain it is, That the present Age is so well versed in Arithmetick, as to compute, That scarce any Timber can be permitted to stand, but to great loss in Forbearance; Whereby, All that owe Money, or marry Daughters, do but discreetly (if they may) to strip their Estates to the last stick; And we know, how few Landlords are now except from both these conditions: So that one would almost marvel, how there should be any Timber left standing and thriving, where the reasons for felling are so urgent, and the encouragements for preserving it so slender. … But were Interest at a low rate, our Concernment could, in no regard, be so great.”[45]

## 4.2 Early calculations on the profitability of forestry

At the height of the interest-rate-debate, John Houghton (1683; 1701) provided perhaps the first modern calculations on the profitability of forestry in his periodical *Collection of Letters for the Improvement of Husbandry and Trade*. In addition to being an active writer on agriculture and trade, he was a well-known editor, book-reviewer, businessman and fellow of the Royal Society.

Houghton’s particular concern was that his fellow member in the Royal Society, John Evelyn (1664; 1679), and one of the great promoters of English husbandry, John Worlidge (1669), had put too much faith in the profitability of growing trees without any warranted economic calculations. To support his apparently unconventional argument that encouraging the growth of wood within twelve miles of navigable rivers would greatly

[44] Ricardo (1817) assumed that as agricultural output expands, less and less fertile land has to be brought into cultivation. Differential rent is the premium which can be charged for the use of land more fertile than the least fertile (marginal) piece of land being cultivated. In Ricardo’s model differential rents (economic rents) are not going away because population grows, there are diminishing returns in agriculture, the supply of land (with respect to quality and location) is inelastic and all land is used to produce the same output (grain).

[45] Similar argument had been presented previously by Thomas Culpeper Senior (1621) who had proposed to the English Parliament for a reduction in the interest rate. His assertion was that a high interest rate makes the land itself of small value, so that men do not seek by industry any more to improve it.

prejudice private and public wealth in England because other forms of land use yielded more value in these relatively easily accessible locations, Houghton presented several numerical examples which were based on the idea that the profitability of different forms of land use can be compared by capitalizing the income streams they are expected to yield. While presenting the economic comparisons that involved the opportunity cost of continuing forestry, he also came very close to expounding the underlying principle of the Faustmann condition (**I**).

To understand Houghton's ability to provide perhaps the first modern forest economic calculations, it is useful to bring out that by the time he wrote his first essay on forestry, the concept of present value for future income streams was widely understood. Through his intellectual networks and business activities Houghton must have been well informed of this line of economic reasoning. Indeed, some of the numerical examples that he put forward in 1683 with the aim to prove that trees were not a profitable crop in England near navigable rivers, appear in form quite similar to the worked examples that can be found for example in Richard Witt's *Arithmetical Questions* (1613).

Another relevant point is that Houghton may have been aware that Sir William Petty ([1672–1673] 1997), an original and active member of the Royal Society, had radically proposed that half of the royal forests should be cleared and the land allocated for other uses (p. 127–128). Even more remarkably, Petty had treated tree planting as an investment in his passing reference:

> "If planting of a tree cost but 3 pence, and timber be worth 10*s*. [shillings] per tun, there is a profit. There is a profit in this proposal, reckoning interest upon interest for 5 years, doubling the principal every ten years by progression". (Petty 1672–1673] 1997, vol. II, p. 127) [46]

A collection of Petty's (1623–1687) occasional papers, covering an extraordinary range of subjects, was first published only in 1927, but Petty, a large landowner himself in Ireland, may have circulated them (or the underlying ideas) among fellow members of the Society. Along with Petty's close friend John Evelyn and Samuel Pepys, Houghton was among those active fellows that shared common interest in forestry. As it happens, Houghton published his first writing on forestry only three years after he had been elected a fellow in 1680 on the recommendation of Robert Hooke, one of the most prominent natural scientists of the time.

About a decade after Houghton had put forward his remarkably modern calculations on the profitability of forestry, Child (1693) reformulated his arguments for lowering interest rates. He now expressed the idea of the opportunity cost of standing timber stock, when he pointed out that Parliament had in the past desired and encouraged the preservation of wood and timber, but with the prevailing high interest rate, no man could afford to raise trees to any size; for after they came to a possible selling value of 40 or 50 shillings per acre, the loss due to holding them mounted faster at 10 per cent interest than the trees themselves grew.

> "It has been the wisdom and care of former Parliaments to provide for the preservation of wood and timber; for which there is nothing more available than the calling down the high rate of usury; for as the rate of money now goes, no man can let his timber stand, nor his wood grow to such years growth as is best for the Commonwealth, but it will be

[46] Petty assumed a forest rotation of 50 years but did not articulate the interest rate. Since 'tun of timber' [a volume measurement] required three trees and 1$s$. [shilling] equaled 12$d$. [pence], an interest rate of five percent induced $NPV = 120d - 3 \cdot 3d(1.05)^{50} \approx 17d$. Petty did not account for the opportunity cost of bare land.

> very lossful to him; the stock of the woods after they are worth forty or fifty shillings the acre, growing faster at ten in the hundred, than the woods themselves do." Child (1693 [1745, 238])

This statement may be regarded as one of the earliest implicit references to the single rotation framework. It might have originated from Child's own experiences in timber trade: he had amassed a considerable fortune in the 1660s by supplying the navy with timber and provisions. An alternative and perhaps more plausible explanation is that Child was aware of Petty's articulations and/or of Houghton's seminal writings on the profitability of forestry.

Another relevant point is that by the time Child (1693) published the amended version of his second pamphlet (the original had appeared in 1690), for example Locke (1691) had presented a detailed analysis, in which he asserts as common knowledge that the value of land depends on the stream of rental income that it generates. Also the similarity of rent and interest in relation to various "stocks", artificial and natural, had been recognized in the economic discussion. Consider, for example, the succinct statement by Nicholas Barbon (1690, 20): "Interest is the rent of stock, and is the same as the rent of land: The first, is the rent of the wrought or artificial stock; the latter, of the unwrought, or natural stock."

To put the contemporary forestry discussion and particularly Houghton's unconventional arguments in a broader context, it is useful to point out that a large portion of English forests had already disappeared by the early fourteenth century due to substantial population increase. The development in which woods, pastures and other marginal lands on the peripheries of anciently settled villages in the country were converted to arable has been described as the 'journey to the margin' (e.g. Bailey 1989). Especially in the south, extensive woodland were often saved from agricultural conversion only if they were granted Royal Forest status. Although the main aim of such forests was to preserve the king's hunting grounds, the special laws and courts that ruled over the Royal Forests often granted the selective harvesting of wood and other non-timber products from the forests provided that it restricted deforestation and conversion to agriculture (Birrell 1980; 1987).

### 4.3 The discovery of the Faustmann formula in England

The general debate on interest rates lost intensity towards the turn of the eighteenth century as a more liberal spirit began to transform English political, financial and commercial life in an unprecedented way. By the time Houghton's second writings on forestry appeared in 1701, England had surpassed the Netherlands as perhaps the most progressive nation in incorporating theoretical advances into commercial and financial practice. The increasing interest in stock exchange trading, especially in long- and short term public securities, led to the active use of several financial innovations such as derivative contracts (e.g. forwards, futures, options) but at the same time also towards more speculative market participation by the investing class.[47]

[47] Houghton (d. 1705) was among the first to give weekly accounts of agricultural and stock prices as well as exchange rates, to consolidate the Exchequer funds tables, and to write articles on the history and current practices of the emerging London Stock Exchange (Neal 1990, 17–18, 22–23; Murphy 2009, 97–113). In the mid-1690s he also provided quite a modern description to the valuation of joint-stocks and derivative securities. Many of the modern financial practices and instruments were actually exported from Holland and its prosperous capital Amsterdam ('t Hart et al. 1997).

In 1720 this development culminated as the South Sea scheme, one of the biggest economic bubbles in modern history, caused the London stock market to reach extravagant high levels. The enthusiasm in the stock market spread to land markets, and for a few months the purchase prices for land soared to double or more than double their previous level (e.g. Clay 1974). Although the scheme collapsed in the same autumn with drastic consequences for some investors, it had greatly increased interest on valuing investment opportunities and a wide variety of paper titles according to their discounted yield, risk and inconvenience (illiquidity).

Several extensive and accurate tracts were published to provide investors with such information. One of the most impressive treatises was prepared by Richard Hayes (1726; 1727) whose book contained manifold tables and examples on valuing annuities on single or more lives and reversion of lives, various leases of land as well as rents of buildings and houses. It may well have been, as Hayes himself claimed, the most extensive and practically oriented treatise on the subject yet to appear in print. Compound interest was almost exclusively applied; the only exceptions were interest payments in periods under one year ("from a day to a year") in which simple interest was utilized (for a similar practice, see e.g. Mabbut 1726).[48]

The book by Hayes was part of the rapidly growing publishing industry in the early eighteenth century, but it is somewhat doubtful how much influence it – and other books written at the time to explain real estate valuation principles – had upon the purchase rates that actually prevailed. Such tables may have been used quite extensively to value leases and properties in commercial London, where the real estate market underwent significant changes towards market orientation in the late seventeenth and early eighteenth century, but were probably less used in the countryside considering the high level of illiteracy, unexpected movements of agricultural prices and uncertainty about a continuance of a particular rate of land tax (Bendall 1997).

However, also in the countryside there started to be a growing class of professionals, lawyers and stewards, who managed the affairs and estates of large landowners and were responsible for maximizing rents and estate yields. One of the defects they recognized in contemporary land markets was the leasing system in church, college and chapter lands (copyholds). The problem originated from the fact that at any point of time every church and college landlord had a scale of years' purchase to be charged for grants or renewals of any particular duration. In the century after 1660 the above system invariably gave the lessees an extremely good bargain because the lease values were calculated on the basis of an unrealistically high rate of interest (Clay 1980, 133–134).[49]

The overly generous leasing system in church and college lands was among the first openly criticized by the bishop of Chichester, Thomas Manningham (1712), who demonstrated the financial losses that the low lease prices induced to the church and clergy. His calculations with year' purchase indicated that the church applied an interest rate of 9–10 percent in renewing leases, whereas the market rate for sales of land suggested that the interests rate should have been much lower, five or six percent. Manningham realized that

[48] Note that simple interest is still conventional practice in those loans that involve annual or more frequent interest payments. If interest is let to accrue more than one year, repayments typically include 'interest on interest'. Simple interest is also applied in modern financial markets for determining prices of fixed income securities with less than one year to maturity (Poitras 2000, 147).

[49] A copyholder was a tenant who held his land by a written agreement, the terms of which were defined by a copy of the manor court record. Copyholds came with many varieties; some were held for term of years, renewable at a certain period of years, others were for life or lives, also renewable (Richards 1730, 5–6; Franklin 1948, 86–87; Overton 1998).

this difference induced a huge income transfer from the church to the lessees in the form of fines and land rents.[50]

Richards (1730) contributed to this discussion in his main work *Gentleman's Steward and Tenants of Manors Instructed*. His principal aim was to supply "rational and easy rules and tables for finding value of estates of freehold, copyhold and leasehold", but in retrospect his most pertinent merit was that he presented valid calculations on forest value under both sustained yield and intermittent management. As Richards put it: "I have laid down some rules of judging the worth of timber trees and coppice wood…" (p. xiij). The treatise was ready for print in 1727 except for the most laborious tables involving valuation of annuities on lives according to the principles that a few years earlier had been laid down by Edmond Halley and Abraham de Moivre, at the time leading figures of the English scientific community (p. xiv).

Although Richards' three examples on forest valuation were condensed into two pages in the last section of his treatise (p. 90–91), thus appear like passing references, he showed keen interest in matters of forestry. Besides advertising his services in timber inventory and valuation in the cover page of his impressive book ("Lands, Buildings, Timber, and Artificers Work are Survey'd, Map'd and Value'd by the Author"), he pondered proper risk-adjusted interest rate in valuing timber and calculated growth rates of oak trees based on his own experiments (p. 85–89). Moreover, in an appendix he explained the principles of *Micrometer*, a sophisticated geometrical instrument that he had developed for measuring timber volumes in standing trees. Interestingly enough, Chambers (1612) had developed and Hossfeld, Faustmann and Pressler would develop similar instruments.

An important additional incentive to survey and value all kind of landed property came from the contemporary financial markets. Many investors who had gained fortunes in London City during the first decades of the eighteenth century turned to pursue more risk-averse investment strategies that not only could generate a regular flow of income, but also would diversify their portfolio of assets and improve their social status (Murphy 2009). Since land continued to be regarded as a relatively stable investment and had a symbolic importance, those describing themselves as 'gentleman' (the term being adopted by wealthy merchants and other professionals) directed increasing interest in the purchase of landed property and thus survey and valuation of manors, estates and accompanying woodlands according to the same principles as they were accustomed to do with their other business ventures. It was in this particular field that Richards showed great competence.

### 4.4 From land values to optimal timber harvesting

Culpeper Snr (1621), Culpeper Jr (1668), Child (1668; 1693) and Petty (1672–1673) may qualify as the first English commentators who presented rudiments of modern forest economic reasoning, but it was John Houghton (1683; 1701) and John Richards (1730) who appear as the true pioneers of this line of natural resource economic thought. There is,

[50] 'Fines' were lump sum payments through which tenants were expected to purchase most of their tenancies (lifeleaseholds). Thereafter they rendered only a small annual rent representing a mere fraction of what their land was worth (Clay 1981). Landlords who took fines were actually obtaining an advance payment of rent, or to look at it in another way were selling their tenants annuities, in the form of the income that their farms could be expected to yield, for the term of their leases.

however, no evidence that their modern reasoning would have inspired a construction of a more systematic forest economic framework in England.

In the subsequent decades, there seems to have been only sparely discussion about modern economic aspects of forestry in England, perhaps because of the gradually decreasing role of the sector in the country (see James 1981). The domestic forests simply melted away with the growth of population and overuse, and the country became even more dependent on timber imports. At the same time, the transition to new manufacturing processes began to transform local economies. From about the mid-eighteenth century Britain entered the era of so-called Industrial Revolution which not only induced the change from wood and charcoal to coal, but directed increasing attention to the role of capital and labor as production factors besides land. Similar shift of emphasis in regard to inputs occurred in agriculture.[51]

In forestry, outstanding examples of the increasing emphasis on the marginal returns of capital are the writings which addressed the most profitable felling age in forests. Without any reference to earlier observations, a large landowner Richard Watson (1794) proposed in his agricultural report that a tree should be cut down when its marginal value growth rate is less than the interest rate.[52] This argument was some years later noticed by William Marshall (1808) who served as one of the prime reporters to the Board of Agriculture. While commenting on what he found when visiting different areas of the country and reviewing the complied regional agricultural surveys, he added a brief remark on forestry to Watson's report: "together with the annual value of the land it grows upon".

Thus Marshall recognized the fact that trees require land while they are growing and that new trees cannot be planted until old ones are cut. Therefore, postponing the next harvest (and investment in a new generation of crop) also postpones all subsequent harvests (investments). To take this aspect into account, one has to consider an infinite chain of rotation periods or, alternatively as Marshall did, extend the single rotation framework to account for the opportunity cost of bare land (see e.g. Samuelson 1976). Note however that if forestry does not yield a surplus (bare land value is nonpositive), there are no binding constraints on reforestation and forest land does not have alternative uses, the single rotation approach applies.[53]

Where did Watson and Marshall derive the modern idea of applying marginal approach in forest resource allocation? Before taking up the post of Bishop of Llandaff (in northwestern England) in 1782, Watson was a distinguished academic at the University of Cambridge and was elected a fellow of the Royal Society in 1769. Through his intellectual networks he may have well become aware of earlier accomplishments in the field. His

[51] The English Agricultural Revolution, usually dated about 1690–1800, increased agricultural productivity through various technological innovations and institutional changes. Since it released labor for other purposes, it has often been regarded as one of the factors contributing to the Industrial Revolution. Overton (1998) argues that the transformation of agrarian economy in England was a more extensive and enduring phenomenon that took place from 1500 to 1850.

[52] Watson (1794) made the following observation: "If profit is considered, every tree of every kind ought to be cut down and sold when the annual increase in value of the tree, by its growth, is less than the annual interest of the money it would sell for." For details, see James (1981, 176–177) and Scorgie and Kennedy (1996).

[53] Many prominent economists (Jevons 1871; Wicksell 1893; Fisher 1907, 160–163; 1930, 161–165; Boulding 1935) have proposed the single rotation solution because they have assumed that growing of trees is analogous to maturing of wines (and cheese). This comparison of course discards the fact that trees reach maturity only as a standing stock on the same piece of land where they have been planted, whereas in wine-aging the significance of bare land is more negligible and the maturing process occurs on other piece of land than that is used for actual grape production. The fermentation containers and facilities, rather than land, represent the capital necessary for maturing wine.

autobiography reveals that he was familiar with the writings of John Evelyn whom he criticized for forgetting to take into account “the increase of money at compound interest” when adducing the advantages of letting oak woods stand until great age (Watson 1818, 303–304). Similar point, of course, had been raised more than a hundred years earlier by Houghton who at the time served on the Royal Society’s committee for agriculture. Another interesting observation is that Watson’s agricultural report in 1794, dealing with agricultural conditions and practices in the county of Westmoreland, contained similar calculations to those of Houghton with regard to future value of forest stands.

William Marshall, in turn, had commenced his first agricultural survey in 1783 while serving as an estate agent. His two-volume comprehensive report on the rural economy of Norfolk was published four years later – it contains 775 pages of which 62 pages can be classified as economics (Taylor and Taylor 1952, 331). Marshall’s (1745–1818) competence as an estate manager and agent raises the question of his familiarity with Richards’ (1730) writings, which, in the field of estate surveying and appreciation are even in modern standards of remarkable merit. Considering that Marshall and his great rival Arthur Young were the leading English agricultural writers of the late eighteenth century, it seems quite evident that both of them were aware of Houghton’s seminal accomplishments in agricultural publishing – Young (1783, 5) certainly was (see also Kerridge 1968). It seems plausible that they also had knowledge of Houghton’s innovative calculations and unconventional arguments on the profitability of forestry.[54]

# 5 TOWARD MODERN FOREST RESOURCE ECONOMICS

## 5.1 Elements of economics in early forest science

It apparently took several decades until the modern forest resource economic ideas and principles introduced by Houghton, Richards and Marshall were rediscovered in the ‘scientific forestry’, i.e. more rigorous and systematic treatment of forestry that emerged in Central Europe from the mid-eighteenth century, and much longer until they were incorporated as a fundamental part of the discipline called ‘forest economics’. The first delay was at least partly due the fact that the development of economic thought followed quite different course in German states and principalities than in England. The German political and economic development from the late seventeenth century was profoundly influenced by cameralism, a doctrine which emphasized national self-sufficiency and government intervention in allocating resources. Accordingly, forest regulation and planning (*Forsteinrichtung*) and its fundamental quest for sustainable and regular flow of

[54] The first volume of *Annals of Agriculture*, collected and published from 1783 by Arthur Young, includes an interesting short communication *Observations on Planting and the Growth of Trees* by some Edward Harries, an estate owner near Shrewsbury. He notes that annual rent on better lands, for any given time, can be so high that if compound interest is applied, tree-growing may not be profitable (see Young 1783, 389–393). This was essentially the same argument that Houghton had substantiated a hundred years earlier.

timber in a long term became the prime concerns and targets in forest policy and forest resource management (**II**).

In line with these views, it was the desire to value fully regulated or normal forests with constant annual timber and other income in perpetuity that inspired the first revelations of modern forest economic reasoning in the German tradition. The idea of valuing forests by the discounted future income they are expected to generate in sustained yield forestry was apparently first laid down by the famous German academic cameralist Georg Heinrich Zincke (1755) in his extensive treatise *Anfangsgründe der Cameralwissenschaften* (*Foundations of Cameral Science*). Zincke's statement on forestry was relatively brief, only few pages, and since he made no reference to earlier contributions in the field, it is difficult to say whether he was aware of Houghton's and Richards' writings. A few years later Wilhelm von Moser (1757) echoed Zincke's views in his *Forst-Oeconomie* (*Principles of Forest Economics*) – a textbook which has been regarded as the first treatise on forest economics but which almost exclusively focused on promoting prevailing cameralistic ideas of forest regulation and management (**II**).

It appears that other distinguished German proponents of 'scientific forestry' in the latter part of the eighteenth century did not essentially contribute to the development of modern forest economic thinking, even though many of them were mathematically inclined and certainly had tools for more explicit contributions in the field. Their prime interest was focused on other key aspects in this emerging discipline, such as measuring timber volumes, developing more advanced methods for forest inventories and constructing more sophisticated techniques of forest regulation.

It was Johann Wilhelm Hossfeld (1805b) and Gottlob König (1813; 1835; 1842) who seem to have introduced the fundamental forest economic principles underlying the Faustmann formula and Faustmann condition in the German tradition and to apply them in calculations of forest values and most profitable felling time (**III**). König's additional merit is that he seems to have been the first who correctly included income from thinnings as well as annual management costs in calculations of forest land value. Their insights and contributions paved the way for Faustmann's (1849a; b) and Pressler's (1859; 1860) more analytical and comprehensive accomplishments in the field.

### *German polity, economy and resource economics*

The relatively late forest economic revelations in German scientific forestry and early forest science, compared to similar manifestations in England, deserve further attention. The substantial time interval may be understood in the context of rather different political ideologies and socio-economic conditions which had far-reaching impact also on the development of more general resource economic though in these two countries.

During the first part of the eighteenth-century, England, though already a leader among commercial nations, was still predominantly an agricultural society (Thirsk 1985). However, the relatively liberal political and economic environment that had taken root in the last decades of the seventeenth century served as an introduction for even more significant changes in the English society. From about 1760, new modes of manufacturing began to transform production processes, markets and societal structures in a revolutionary way. This development inspired also classical political economists to propose more liberal approaches to the contemporary economic policy. The most prominent exponent of this line of economic thinking was, of course, Adam Smith (1776) who opposed the prevailing mercantilist orientation (emphasizing positive balance of trade and inflow of bullion by means of state regulation and intervention) and advocated for a *laissez-faire* type of economy which is based on individual self-interest and free markets. His most famous metaphor was the "invisible hand", a concept which he actually used only once in his *Wealth of Nations* (1776) and which had also appeared in his other major work, *Theory of Moral Sentiments* (1759).[55]

Compared to England, Germany at the turn of the nineteenth century was economically an underdeveloped country: some eighty percent of the population was agricultural and the industrial revolution had barely begun (Betz 1988). It was neither a political nor an economic unity, rather a mosaic of hundreds of territorial states, where the extent of the market was rather limited and individual states showed a great variance in political, societal and economic structures and abundance of natural resources. Moreover, many German states and regions had suffered severely from the Seven Years' War (1756–1763), one of the major conflicts in Europe, and again, from the successive Napoleonic wars (1803–1815).

The quest of sovereignty and the pressing social problems in many German states supported the traditional cameralist perception that the concept of self-interest represents the pursuit of purely private economic interests in a way which is detrimental to the power and cohesion of the state and ultimately also to the overall welfare of the society. In his *Forest Economics* Bernhard Fernow (1902, 1–5) condenses the idea of the state as the guardian of the distribution of welfare among present and future members of the society.

> "[The state] is not to be regarded as merely the arbiter between its present members, but it becomes the guardian of its future members; government becomes the representative, not only of present communal interests, as against individual interests, but also of future interests as against those of the present. Its object is not only for the day, but includes the perpetuity of the well-being of society,…".

This view resembles modern argumentation that various market imperfections hinder pure market economies from achieving efficient and fair distribution. The resulting claim has been that government inference is needed to secure a sufficiently long view and broad perspective in decision-making. This contention of course gives rise to the fundamental question to what extent government intervention in the economy can help to achieve this aim (see e.g. Solow 1974).[56]

By the 1830s, the economics taught and published in Germany was pragmatically eclectic, drawing widely on contemporary English and French political economy, but simply integrating this work with existing German work on the subject (Tribe 2003). The leading German textbook was Karl Heinrich Rau's *Lehrbuch der politischen Oekonomie* (*Principles of Political Economy*), the first volume being published in 1826, reaching its ninth edition in 1876. Although Rau incorporated elements of the Smithian political economy and tried to integrate it with cameralistic ideas of state intervention and ethical restraints on self-interest, his book enumerates economic objects rather than presenting instruments of economic analysis (Tribe 1988). Also the early important theoretical followers of the physiocrats and English political economists in Germany – Friedrich

---

[55] For a description of mercantilism, see for example Magnusson (2003). As cameralism, it dominated economic and political thinking in the seventeenth- and eighteenth-century Europe and evolved over time. Both were relatively loosely formulated practical doctrines; they encompassed a set of ideas and guiding principles how to furtherance national wealth and power.

[56] For a discussion how the economic role of government has been perceived throughout the history of economic thought, see Medema (2003).

Hermann and Johann Heinrich von Thünen – were very careful in their writings and teachings to complement it with appropriate German adjustments, such as ethical considerations and restraints on self-interest (Betz 1988).[57]

The revolutions in 1848–1849 in the German states induced that, for a few decades, liberal ideas flourished, propounded by journalists and political personalities (Dickinson 1969; Betz 1988). The new spirit also spread to economic life: new enterprise laws were passed and corporations began to be formed. Before, joint-stock companies had been rare in Germany (Kindleberger 1985, 210), which was in striking contrast to the situation in Holland and England. In Holland, the first permanent joint-stock company had been founded almost 250 years earlier, and there had been a flurry of forming similar companies in England at the turn of the eighteenth century.

However, the wave of liberalism was only temporary in German political and economic life. After the unification of Germany in 1871, the theories of classical political economy and its *laissez-faire* basis became increasingly unpopular both in German economic policy and academic circles. The orientation that began to dominate German economics was the "historical school". Broadly speaking, it represented a national mainstream that was skeptical of classical economics as understood in Britain and France, especially of its attempts to construct a deductive "mathematico-economic" science. Proponents of the historical school typically argued that classical economists assumed that their axioms represented "the natural laws of economic life", i.e. universal economic laws that were valid for all times and places (Tribe 2003). The critical attitude toward general economic theory reflected contention that different nations at different stages of development have different ideals and therefore require different policies – and Germany at the time was a young and underdeveloped country compared to England, the leading western nation with thriving industries and trade and a relatively well-developed market economy.

The historical school made attempts to found economics upon an inductive basis by claiming that economic analysis could not be derived from general principles as in natural science, but must rise from the study of individual economic action in reference to diversity of economic circumstances and contemporary institutions. Although their efforts to build a coherent theoretical basis proved inconclusive, the underlying views later contributed to the development of American institutional economics, the early exponents being Thorstein Veblen and John R. Commons (Rutherford 2001; Tribe 2003).[58]

## 5.2 Critique and revival of the Faustmann model

The aforementioned political and socio-economic environment in Germany provides a historical background against which the emergence and development of forest economics during its formative years should be understood. Although Faustmann (1849b) and Pressler

[57] Smiths's *Wealth of Nations* (1776) became an immediate success in England but the first German edition, published in 1776–1778, was largely ignored by the cameralists and had only little impact on German economic discourse (Hagemann 1996). However, after the second and higher quality German translation was published in 1794–1796, the Smithian doctrine was discussed on a much broader scale. A particular role was played by the universities of Göttingen and Königsberg, of which the first had a high number of British students. Among the students were also many Germans who later became liberal reformers or well-known economists such as Thünen.

[58] For a more extensive discussion on the eighteenth and nineteenth century German economic tradition and its background and international influences, see e.g. Betz (1988), Tribe (1988; 2003), Augello and Guidi (2001), Hagemann and Rösch (2012) and Cardoso and Psalidopoulos (2016).

(1860) published their classical contributions during the short period of liberalism in Germany, their works received strong criticism among eminent forestry scholars and professionals right after their introduction. Due to the dominant role of German forest science and educational system, this attitude spread also to other countries.[59]

One of the primary reasons for the persistent professional reluctance of using the Faustmann model relates to the supposed special nature of capital and investments in forestry and thus to discounting income streams and utilities far into the future. A popular claim in the field of forestry has been that regeneration costs can be deducted from the harvest income at the end of the preceding rotation, especially in sustained yield management, and thus conventional investment calculations employing compound interest and stretching far into the future are not appropriate. This perception has given rise to the doctrine of 'forest rent' (*Waldreinertragslehre*) saying that all that matters in forestry is the net annual operating income.

As noted by Hiley (1930, 161), the expression 'forest rent' is misnomer which has unfortunately acquired a secure position in the terminology of forest economics. Pursuit for the highest annual net income implies that the rate of interest is zero which leads to longer rotations and generally also to more capital-intensive forest management than the Faustmann formula.[60] This point was stressed by Pressler, who combatted the use of forest rent maximization as an optimum criterion and wanted foresters to take interest into account (see e.g. Dickson 1956). He strongly recommended a forest policy aiming at maximization of the land value; an idea that was perhaps first put forward (though only verbally) in the German forestry literature by Wilhelm Friedrich Pfeil (1823, 322), an eminent figure in the early nineteenth century Prussian forestry and one of the 'classical writers' in the discipline. However, in his later writings Pfeil turned to oppose the land rent theory (*Bodenreinertragslehre*) and thus associated with the view which would become dominant among forestry scholars and professionals for the next hundred plus years.[61]

The essence of the issue is fairly nicely condensed by Hiley (1930, 164): "There may be many reasons for extending the rotation beyond the strictly financial rotation, but the rotation of highest net income [forest rent] has no special attractiveness from an economic point of view and cannot, therefore, be defended on any economic ground."

Another common argument fostered in early forest science (and among its professionals until present days) is that forestry does not ordinarily start with bare land; in many cases the original timber stock has been granted for free by former generations or by the nature (*Naturgaben*). This has given rise to an approach which omits regeneration costs at the beginning of the first rotation. It is useful to point out, however, that even when the initial generation of crops can be achieved without costs (as sometimes in natural regeneration), from modern resource economic point of view the achieved growing stock still presents capital with opportunity costs.

---

[59] For related discussion, see e.g. Streyffert (1938), Dickson (1953), Hasel (1985), Löfgren (1990), Möhring (2001), Hasel and Schwartz (2002) and Hyytiäinen (2003).

[60] It can be shown that the Faustmann rotation reduces to the solution of maximum forest rent when implementing an interest rate tending to zero.

[61] Pfeil (1823, 322) stated: "The point of time that generates the largest financial yield for the wood shall be determined as follows ... For each rotation, one calculates the value of land with exclusion of the already standing timber." "Das Verfahren, um die Zeitpunkt zu erfahren, in welchem das Holz mit dem grössten Geldertrage zu benutzen ist, wird wie folgt sein müssen … Man berechnet für jeden Umtrieb den Werth des Bodens mit Ausschluss des schon jetzt darauf stehenden Holzes." For early references to this statement, see Heyer (1871, 69) and Schwappach (1888, 824).

Third point of critique has been that the standard Faustmann formula assumes continuing forestry (and thus reforestation). The argument is that this setting does not provide adequate basis for investment calculations if switching from other forms of land use (agriculture, wasteland etc.) involves non-recurring initial establishment and afforestation costs. Navarro (2003) discusses how the inclusion of original investment in land improvement and afforestation costs (establishing a forest) affects optimal forest rotation. Obviously, the standard Faustmann model can be modified so that is copes with different alternatives with regard to initial investment in establishing a new generation of forest crop or in converting forestland to some other use that pays positive rent.

A fourth argument has been that the classical Faustmann model abstracts from the special economic interests or preferences of individual forest owners. Quite remarkably, this important point was brought up already by Faustmann (1849a) in a newly discovered article which deals with forest valuation (**IV**). The article also demonstrates how the most profitable cutting time can be determined with differential calculus, though it does so without explicitly accounting for bare land.[62]

An equivalent modern argument would be that nonindustrial private forest owners may have diverse attitudes toward risk or that their decision-making involves more or less intangible factors which are largely psychological or personal in nature ("home-value", congenial environment, societal tradition etc.). Although such preferences are not restricted to forestry, they are a prominent feature in it because the production process involves a large spectrum of non-market outputs with uncertain economic, societal and environmental effects and is attached to land – the durable ('indestructible' as Ricardo called it) and immovable factor of production capable of a succession of annual incomes and benefits in perpetuity.

Since forest owners' preferences may vary across generations – also with regard to the treatment of the same physical forest stock – the conventional 'infinitely lived agent model' (the standard Faustmann model) may not appear a realistic approach to capture optimality in management. However, the potentially complex economic setting involving variable preferences across generations may be treated at the level of private forest owner as a finite-horizon problem if one assumes perfect information and perfectly competitive land and capital markets. The interpretation is that the owner can manage his forest property according to his preferences and, at any point of time, can sell it in perfect land markets. In real-world situations, however, there may be several factors (e.g. nonmarket goods and services, high information or transaction costs, nonneutral taxation) that render perfect land and capital markets implausible.

From the perspective of whole society, the intergenerational setting in forest resource management is even more profound because land forms a permanent part of society's endowment, and because some of the outputs that forest ecosystems provide are public goods with definitive or potential life-supporting role. The latter property, in particular, brings out the formidable question of the substitutability between (critical) natural and other forms of capital, an issue that is at the heart of the enduring debate concerning sustainability and resource economic analysis.[63]

---

[62] For a modern interpretation of Faustmann's early calculations on the most profitable cutting time, see Appendix 2.

[63] For recent reviews of the role and treatment of the concept of 'land' (natural capital) in classical and neoclassical economic theory, see Hubacek and van den Bergh (2006) and Gaffney (2008).

*Discounting in dispute*

Some observers (e.g. Gaffney 2008) have claimed that even today foresters dislike compound interest because timber culture is so capital-intensive that it needs a low rate of interest to justify itself in competition with rival uses of land and capital – and foresters are in the business of justifying timber culture. On the other hand, special attention on the choice of discount rate is not surprising given the importance of this single parameter in forestry. Forest land values and optimal rotation periods are typically highly sensitive to discount rates, and long investment periods in forestry induce that rates common in other sectors of private industry tend to wipe away the distant benefits from young and future crops.

Almost a hundred years ago young Bertil Ohlin (1921) pondered the pertinent question: "why is so much actually paid for the forests that it is impossible to obtain profitability according to normal rate of interest?" He concluded that it is probably true that this does not exclusively depend on ignorance [of the Faustmann formula]; there might also be real reasons for 'the overpayments'. Since some of these reasons were already mentioned by Richards (1730, 5) and Faustmann (1849a) and have regularly appeared in forestry literature ever since, also as a critique of relying on the Faustmann condition, it is useful to reiterate Ohlin's observations also here.

Ohlin identified three common perceptions for the rationale of the overpayments. First was that forest purchase forms an investment which combines a considerable degree of safety. He found that this being the case, the forestry's somewhat lower rate of interest, compared with the interest of bonds, might be justified. This line of argumentation coincides with foresters' long-standing practice to use a special interest rate in forestry, *forstlicher Zinsfuss*, which usually leads to higher land values, longer rotations, higher stocks of standing timber and higher timber flows than common interest rates. The general contention has been that buildings, machines and other man-made capital wear out and their yields are subject to various interruptions and shortfalls, whereas land, at least in principle, has the potential to maintain its productivity and yields continuously and permanently.

Another apparent motive for using *forstlicher Zinsfuss* has been that at any probable market rate of interest, the returns from forestry, at least when traditional management regimes with frequent and slight harvests and long rotations are applied, would fall short of the returns from many alternative investments (cf. Gaffney 2008). These include agriculture on most lands of reasonable fertility and position.

The third motive relates to the fact that much of the forest in Europe was (and still is) maintained by public authorities: states, municipalities, parishes etc. As a result, forests were (are) often treated more as a public service rather than as a business investment. Thus one may interpret the *forstlicher Zinsfuss* to have reflected social values and associated discount rates. The discussion about appropriate social rate of time preference is by no means restricted to forestry in natural resource economics. Griffin (2012) describes similar disputes in the United States during the classical era of water resource economics (1945–1969). More recent controversies concern the intertemporal valuation of the impacts of such critical phenomena as biodiversity loss and climate change. The choice of social discount rate is inextricably linked to the efficient and fair allocation of natural and other resources between present and all future generations and thus involves deep ethical issues (see e.g. Gollier and Hammitt 2014).

Second and third rationale mentioned by Ohlin were the expected rise of timber prices and future improvements in silviculture, both factors implying that the static condition [of the standard Faustmann formula] is not fulfilled in reality. He concluded that a correct answer to the question about profitability is inconceivable as long as the discussion is restricted to static viewpoint. This remark was prescient in a sense that dynamic features of forestry and its operating environment has been a major research topic in the field of forest economics and management during the last decades and shall probably maintain this salience in the future.

*Faustmann enters neoclassical economics*

It was not until about the last quarter of the twentieth century when the Faustmann model began to receive revived interest among forest professionals, first in North America and the Nordic countries. Samuelson's (1976) review article is usually regarded as a turning point in the field of modern forest economics.

Gaffney (2008) asserts that American economists first became aware of Faustmann's work through his dissertation *Concepts of Financial Maturity of Timber and Other Assets* (Gaffney 1957). Jack Hirshleifer circulated it among the economic "elite" and also Samuelson referred to it in his celebrated paper, initially presented at the Economics of Sustained Yield Forestry Symposium held in 1974. One of the five speakers at the symposium was Hirshleifer who discussed the trade-off between sustained yield and capital theory (Hirshleifer 1974; Newman and Wagner 2012). According to Gaffney, especially enthusiastic of the Faustmann model became representatives of the forest industry.[64]

The most essential and enduring merit of Samuelson's review is that it established that the standard Faustmann formula applies to stand-level forest management when a set of assumptions holds: perfect information; perfect capital, timber and input markets; no environmental preferences; no relevant externalities. It also applies to forest-level management if there are no economic, ecological or other interdependencies between individual forest stands. Johansson and Löfgren (1985, 112–121) denote such highly stylized case a "linear forest" since the associated economic problem corresponds to maximizing a linear profit function subject to linear restrictions.

Note however, that if some of the "heroic" assumptions (as Samuelson coined them) underpinning the standard Faustmann formula are violated, optimal harvesting decision can no longer be taken stand by stand and adjusting the initial forest age-class distribution may become economically rational. Some of these points were already raised by early German forestry scholars, which led them, in the spirit of cameralistic visions, to offer formulas and calculations how to allocate harvests so that the perceived optimal age class or vintage structure – a so-called normal, fully regulated or synchronized forest – would be accomplished and maintained. The fundamental (and difficult) question whether it is actually economically optimal to adjust the forest structure toward this stationary state was disregarded, however, and did not receive formal treatment until quite recently.[65]

Although complete resolution to the question of the optimality of normal forest remains open even today, recent research has demonstrated that the generalization of the Faustmann framework to include multiple forest age-classes is an important extension because it not

[64] A curious point is that Hotelling's (1931) seminal article on the economics of exhaustible resources was "rediscovered" that same year by another authority of modern economics, Robert Solow (1974). See Devarajan and Fisher (1981)

[65] Deegen and Seegers (2011) suggest that the idea of sustainability and the quest for forest regulation became institutions for overcoming uncertainties in societies and for promoting the idea of intergenerational ethics.

only allows one to study the question whether (and under what conditions) the normal forest emerges as a stationary state, but also the more general question of the optimal long term evolution of a tree vintage system. By incorporating one of the most important dynamic aspects related to the capital-nature and management of forest resources, the generalized Faustmann framework allows a theoretically coherent way to analyze timber supply, land allocation, carbon sequestration and other important forest- and market-level questions.

In addition to forests and other complex biological resources, vintage capital models occupy an important place in the more general theory of capital and investment, as demonstrated e.g. in Mitra and Wan (1985; 1986), Tahvonen (2004), Piazza (2009), and Khan and Piazza (2012). The similarity originates from the fact that many man-made capital goods (e.g. machinery, buildings) are composed of age classes or vintages that are subject to different productivity due to aging, technical depreciation or technological development. In forestry, corresponding features arise from the biological growth process which transforms forests and their vintage structure over time.

Samuelson's (1976) celebrated review is of indisputable merit. However, the perception that Faustmann's work was relatively vague for over 100 years (see e.g. Brazee 2001) somewhat overshadows the fact that the Faustmann model and its conformity with the rising neoclassical capital and investment theory was remarkably well apprehended already in the latter part of the nineteenth century. Some prominent examples are the works by Heyer (1865; 1871), Judeich (1871), Gram (1876), Holmerz (1876), Kraft (1882) and Endres (1894; 1911). Particular merit belongs to Gustav Heyer, one of the most active early advocates of the land rent theory (*Bodenreinertragslehre*) who published comprehensive textbooks on forest economics and valuation in the 1860s and 1870s. These books are even in modern standards of remarkable clarity and precision. What was lacking, of course, was the conclusive theoretical link to the neoclassical economic theory that Samuelson and his authority would provide.[66]

Similarly, many of those foresters outside Central Europe, who had been trained in the famous Tharandt forest academy – where relentless Pressler lectured from 1840 to 1883 – or who were due to other sources familiar with the application of land rent theory to forestry, disseminated the modern principles of forest resource economics. Some outstanding examples are the textbooks and articles of Ericsson (1896; 1903; 1906) and Heikkilä (1922; 1929; 1930; 1952) in Finland; Hansen (1877) and Grøn (1931; 1943) in Denmark; Petrini (1937; 1946), Streyffert (1938) and Dickson (1953; 1956) in Sweden; Hiley (1930) in Britain; and Roth (1926) and Thomson (1942) in the United States. Most of the early European works were written in German, until 1940s the dominant language in most fields of science, and in other vernaculars than English.

[66] Gustav Heyer (1826–1883) was the oldest son of Carl Justus Heyer, Faustmann's professor at the University of Giessen. He studied forestry at Giessen concurrently with Faustmann and was appointed professor of forestry at the same academic institution a few years later. In 1868 he moved to Prussia to lead the newly established royal Forest Academy in Münden, and ten years later he accepted a professorship in forestry at the University of Munich (Hess 1885).

## 5.3 Anticipation of modern capital and investment theory

After an examination of the emergence and early development of modern forest economic thought, there remains the intriguing question to what extent this intellectual process was connected to the early progression of modern (natural) resource economics and accompanying capital and investment theory. The most interesting issue concerns the possible role of forestry in anticipating modern principles of capital valuation and marginal analysis, including those cases that involve complex age-class or vintage capital structures.

*German exposure*

Irving Fisher's (1906, 205) brief remark on the sophistication of German forest valuation practices appeared in his *The Nature of Capital and Income*, a book that is conventionally regarded as a seminal contribution to modern capital and investment theory. It should be noted, however, that it has the nature of a compilation; similar ideas on capital valuation had been articulated earlier also in the American academic circles. For example Henry Taylor (1905, 185–197) in his *Agricultural Economics*, regarded as the first book on the subject in the United States, describes in an explicit manner how the capital value of land and farm equipment is determined.

Bearing the above in mind it is interesting to observe that Taylor and many other early American economists (e.g. John Bates Clark, Richard Ely, Simon Patten, Edwin Seligman, Frank Taussig and Frank Fetter) in the last decades of the nineteenth century were intimately affected by the German economic tradition. They all received part of their economics education in Germany – many studied under professor Karl Knies, one of the leaders of German old historical school and Rau's successor at the University of Heidelberg, who almost certainly was aware of the German forestry practices. Schumpeter (1954, 154) informs that forestry remained a recognized division of German treatises on general economics right into the nineteenth century, and Ely, having become one of the leaders of the early conservation movement in the United States, writes that "Forestry was the main feature of conservation developed in lectures [of Karl Knies at Heidelberg] on practical National Economics and Economics Policy" (Ely 1918, 19).[67]

The first American academic economists studied in Germany because the German university enjoyed quantitative and qualitative supremacy over universities in Britain, France and the United States (Streissler 2001; Tribe 2003). This dominance extended itself also to formal education in economics. Already by the second quarter of the nineteenth century, i.e. markedly before in most other countries, economics had become a well-established academic discipline in Germany, taught to all those aspiring to become civil servants and all those who followed the courses of jurisprudence at the universities. During the middle quarters of the nineteenth century, roughly 1825–1875, when German economics was perhaps the most active sub-discipline within international economics (Streissler 2001), the most dominant figures were Rau (1792–1870) in Heidelberg, Friedrich Hermann (1795–1868) in Munich and Wilhelm Roscher (1817–1892) in Leipzig.

[67] Ely had obtained a doctorate at the University of Heidelberg. His passage refers to the classical tripartite division in German economics, established by Rau and still prevalent in German language academic life: economic theory or national economics (*Volkswirthschaftslehre*), economic policy (*Volkswirthschaftspflege*) and public finance (*Finanzwissenschaft*) (Hagemann 2001; Streissler 2001).

Of these prominent universities, Munich also educated agriculturalists and forest administrators. According to Streissler (2001), Munich professor Hermann quoted Thünen in the 1830s just as frequently as he quoted Ricardo. Owing to this favourable reception, Thünen began to develop his marginal approach, which culminated in his use of differential calculus, initially in the second volume of *The Isolated State* published in the year of his death (Thünen 1850) and again in the last volume concentrating solely on forestry (Thünen 1863).

Also the early leaders in American forestry sustained close connections to the German intellectual and professional life. The first to give a course in forest economics in English language was Bernhard Fernow, a renewed German-born and German-trained forester, who in 1896 was recruited to the University of Wisconsin-Madison by Richard Ely (Smith 1982). Two years later also Henry Taylor joined the same university and began to study under Ely. From his lecture notes in this academic institution, Fernow, who became to be known as the "father of professional forestry in the United States", compiled his landmark work *Economics of Forestry*, the first English-language textbook on the subject. The book is of special interest for two reasons: first, it appeared in 1902 – thus well before Taylor's *Agricultural Economics* (1905) and Fisher's *The Nature of Capital and Income* (1906) – and, second, it demonstrates explicitly that Fernow was fully aware of the German tradition in forest economics, including the Faustmann model.

In all, there seems to have been a close-knit intellectual circle of renewed American economists with considerable German exposure at the turn of the century, that is, prior to Fisher's *The Nature of Capital and Income* appeared: for example, Richard Ely (1854–1943), John Bates Clark (1847–1938) and Frank Fetter (1863–1949) in political economy, Henry Taylor (1873–1969) in agricultural economics and Bernhard Fernow (1851–1923) in forest economics. It is quite possible, even plausible, that Fisher (1867–1947) became aware of the German forest valuation practices through this thriving intellectual community, senior members of which also acted as key figures in founding the American Economic Association. This would explain his curious remark on the early use of capital valuation in German forestry. Similar international network may have motivated John Bates Clark to expound his famous model of permanent capital fund – his prime example of such capital fund being foresters' traditional ideal, a sustained yield normal forest.[68]

*Perpetual capital fund and time element*

In forest economics, perhaps the most controversial and difficult capital-theoretic question concerns the optimal allocation of forest resources under age-class or vintage capital. While individual trees and single even-aged forest stands may be treated within the standard Faustmann model, things usually get much more complicated when multiple stands (or tree cohorts) of unequal age are involved. This kind of vintage capital structure gives rise to various overlapping point-input, point-output processes which may generate economic incentives to smooth harvests over time. An archetypal case of continuous repetition of such processes is the forest in which a fixed number of trees is cut each year and

[68] For a more detailed discussion of the German exposure in early American economics, see Barber (1993; 2001; 2003). Also Fisher had these connections: after graduating in 1888 from the Yale University, he studied in Berlin and Paris. Two years later he returned to Yale and received his Ph.D. in economics. During the 1890s he frequently assisted Arthur Hadley, the Yale professor in political economy who also had studied at the University of Berlin.

simultaneously the same number of seedlings is planted. If the forest is characterized by an even age-class distribution, it can be maintained in an unchanged state year after year.

Foresters have systematically utilized this framework in forest resource management and planning at least from the mid-eighteenth century, but to modern capital theory similar setting appeared when American neoclassical economist John Bates Clark (1899, 313–314) used it as an example of a permanent capital fund and synchronization of production and consumption. His claim was that since planting and cutting are, in a way, simultaneous in such steady-state forest, the long time period involved in the ripening of the trees loses its importance and the time element can be collapsed out of the capital-theoretic framework. This argument implies that the rate of interest in a stationary state is zero.[69] [70]

Clark's reasoning provoked a violent debate at the turn of the century, denoted as the "first great controversy over capital theory" (Blaug 1997, 547). An early explicit statement of the illusionary nature of Clarks's idea was delivered by Eugen von Böhm-Bawerk (1907) who pointed out that synchronization of inputs and outputs, which holds only in a stationary state, makes it appear *as if* periods of production have been eliminated. In retrospect, the debate left the door open for Irving Fisher (1906; 1907) to present a framework what was to become the modern theory of capital and interest; a construction that encompasses the interaction of subjective impatience and objective investment opportunity (Cohen 2008).

Despite Fisher's accomplishments and the harsh criticism that Clark's propositions received, similar argumentation recurred in the second great controversy over neoclassical capital theory. This time it was another prominent American economist Frank Knight (1933, 339; 1934, 275; 1935a; 1935b; 1936; 1938), one of the founders of the Chicago school, and his student George Stigler (1941, 305–315), both future Nobel Prize laureates for economics, who put forward similar argumentation. In his *Production and Distribution Theories* Stigler reiterated the forestry example:

> "We can say that any one row [of trees] takes fifty years to mature, but since there is a constant output of timber forever, there is simply no point in saying it."

Others, for example Friedrich von Hayek (1936, 214) disposed the Clarkian view as "absurd use of words", and the discussion gradually faded away. However, even later Schumpeter (1954, 538–539), in his monumental *History of Economic Analysis*, saw it appropriate to make a distinction between "synchronization economics" and "advanced economics", the latter insisting that production is time consuming.[71]

---

[69] Clark (1899, 131–132) wrote: "Let us, for another example, plant a forest of such slow-growing trees that it will take fifty years to bring one of them to the point of maturity, at which it will be ready for cutting. Let us arrange the trees in rows, and plant one row in each year. … After fifty years [after constructing a normal forest] the cutting begins; and now all waiting is over. We may cut every year a row from the ripe end of the forest and plant a row at the opposite end. From this point on, the long period involved in the ripening of the trees loses its importance. … All the waiting that was done was involved in getting this bit of arboreal capital into the condition in which it should perform its function."

[70] And few sections later (p. 313–314): "Again, let a forest twenty acres in extent suffice to furnish firewood for a family. A tree will mature in twenty years; and the forest must be kept intact, in point of size and maturity, or the supply of wood will fail. Each year we plant a row of trees along one side of the forest, and cut a row from the other. The planting and the cutting are, in a way, simultaneous. We do not burn today the tree that we plant today; but we burn a tree, the consuming of which is made practicable by today's planting. … The fact that is of practical consequence is, that if we have once secured the permanent forest, we need do no waiting for fuel. The identity of the tree that we burn is of no consequence."

[71] For details of the famous Böhm-Bawerk/Clark and Knight/Hayek controversies in modern capital theory, see e.g. Garrison (1990), Blaug (1997) and Cohen (2003; 2008). For a recent recurrence of the Clarkian contention of the nature of capital in sustained yield forestry in modern investment literature, see Helmedag (2008).

The fact that Clark's reasoning perfectly coincides with forester' traditional perception – once the permanent forest that generates a constant flow of outputs (called normal, fully regulated or synchronized forest) has been established, the simultaneous nature of production and consumption in perpetuity eliminates all waiting – raises questions of his possible connections with the German forestry scholarship. A curious point again is that between 1872–1875 Clark studied at the University of Zürich and Heidelberg under Professor Karl Knies. Since Knies undoubtedly was aware of the sustained yield doctrine in German forestry, one may ponder whether Clark actually derived the idea of synchronized forest and its special properties from the German school of forestry.

Even in much more recent forest economic discussion a persistent claim has been that the Faustmann approach is not valid for special cases, such as fully regulated or synchronized forest, because it does not take into account the interdependence between forest stands or other management units. This has given a motivation to construct two alternative models that would apply in sustained yield forest management. The first formulation is the "marginal model for divisible forest capital", originating from Duerr and Bond (1952), Bond and Guttenberg (1953) and Duerr (1990), and advocated more recently by Oderwald and Duerr (1990) and Kant (2013, 2). Another group of studies have taken similar stand by claiming that the Faustmann approach is inherently flawed for forest-level analysis where harvesting, regeneration and management decisions are made simultaneously and continuously in order to sustain timber production. This has given rise to another alternative model of forest management, namely "the profit maximizing model", formulated originally by Comolli (1981).

Although these models, especially the latter one, have been applied extensively as a basis for theoretical generalizations and for empirical computations (e.g. Yin and Newman 1996; 1997; 1999; Yin 1997; 2001; Yin et al. 1998; Yin and Sedjo 2001), both models lead to biased results because young forests are valued by their immediate sale value, not by the present value of the future income stream they are expected to yield. This deviation from modern capital and investment theory is analytically shown in Tahvonen and Viitala (2006) (**V**). The paper also demonstrates how the forest valuation methods that lack solid theoretical foundation distort profitability figures.[72]

An incisive early remark on the issue comes from Fisher (1907, 24):

> "It is clear that to cut young timber which is growing very fast is like killing the goose that lays the golden egg, and to reckon the value of the growing timber as only equivalent to the wood contained in it is like reckoning a live goose equivalent to a dead one."

To retain perspective in regard to the nature and scope of the forestry problem, it is essential to note that the quest for alternative forestry models *per se* reflects a genuine need for more realistic approaches in forest- and market-level analysis. However, at the same time it should be made clear that the need to account for economic, ecological and other potential interdependencies between individual forest stands serves as an incentive to construct a more general Faustmann framework that is able to incorporate such properties – not to abandon the standard Faustmann model if such interdependencies do not exist.

[72] For discussion of similar misspecifications in uneven-aged forest management, see Getz and Haight (1989, 287–295), Tahvonen (2011), and Rämö and Tahvonen (2014).

*Forerunners of marginal analysis*

The introduction of marginal analysis is usually regarded as the dividing line between classical theory and modern neoclassical (actually postclassical) economics. The all-embracing notion of 'economic efficiency' in modern economic theory rests firmly on the principle of marginalism: marginal revenue/utility versus marginal cost.

The triumph of marginal economics, so-called 'marginal revolution', is conventionally credited to William Stanley Jevons (1871), Carl Menger (1871), Léon Walras (1874–1877), Eugene von Böhm-Bawerk (1888; 1890), Alfred Marshall (1890) and Knut Wicksell (1893). However, elements of the marginal approach had appeared much earlier in the literature. Well-known examples are the works of Sir James Steuart (1767), Anne-Robert-Jacques Turgot (1767), Ricardo (1817), Rau (1826), Thünen (1926; 1850; 1863), Hermann (1832), Lloyd (1834) and Gossen (1854), which, with different intensity and emphasis, had treated questions of marginal productivity and marginal utility. Also in the French engineering tradition the marginal approach had been utilized at least since the 1840s, the pivotal figure being Jules Dupuit (Ekelund and Hébert 1976; 1978).[73]

Perhaps the most remarkable early contribution is due to Thünen who in the second volume of his *Der isolierte Staat* (1850) put forward a perfectly modern statement that net revenue is maximized when each factor of production is employed to the point at which its marginal value product (*Mehrertrag*) is equalized to its marginal factor cost (*Mehraufwand*) (see Blaug 1990, 136). Although the discussion proceeds in verbal terms, illustrated by numerical examples, Thünen correctly points out that a marginal product of a factor is a partial differential coefficient of a multi-variable production function. This procedure, of course, conforms to modern comparative statics.

The above account suggests that the development of marginal analysis was a gradual and collective achievement – an intellectual process which does not allow giving merit to one 'great' scientist or professional (see also Blaug 1986, 209–218; 1997, 277–310). In line with this conjecture are the contributions of Houghton (1683; 1701), Watson (1794), William Marshall (1808), Reventlow (1810), Thünen (1826) and König (1835; 1842). Also their achievements indicate that some alert scholars may have, consciously or unconsciously, used the marginal method in practical situations long before it became a formal part of the neoclassical economic theory. The first ones to apply the method more rigorously in forest economics by using differential calculus seem to have been Faustmann (1849a) and Thünen (1863), though also Hossfeld (1805a) had apparently made use of similar calculus when he derived the forest rotation age that maximizes timber production (maximum sustainable yield).

Those early agriculturalists and foresters (Houghton, Marshall and König), who first grasped the marginal reasoning behind the Faustmann condition, invariably relied on the formulation that incorporates bare land as a distinct capital component besides standing timber. This is an intuitive approach in a sense that it explicitly reveals that an increase in the felling age of trees involves an economic compensation for the capital tied in standing timber *plus* bare land, the latter in the form of rent (or interest on the price of the land).

Even later, despite the fact that mathematically inclined early 'forest economists' (Hossfeld, Faustmann, Pressler) mastered differential calculus, the approach making use of exogenous bare land values was a simple and convenient way to determine the optimal

[73] For a more comprehensive review of the proto-neoclassicists before 1870, see e.g. Blaug (1997), Sandmo (2011) and Ekelund and Hébert (2014).

felling age when explicit timber (value) growth functions were not readily available, as noted by Faustmann (1849a; 289, 292). Another contributing factor for its adoption was foresters' desire to include income from thinnings which extension would have complicated differential calculations involving infinite time horizon. According to Heske (1938, 28), the financial importance of thinnings gained recognition among German foresters toward the mid-nineteenth century. Bertil Ohlin (1921) may have been the first to derive the correct optimal rotation solution under continuous time by maximizing land value, but like other prominent economists before and after him, he relied on a highly stylized objective function that neglected thinnings.

The final word about whether Houghton, Marshall, Hossfeld, König, Faustmann and Pressler anticipated modern marginal analysis in intertemporal production-consumption framework would require far more scrutiny and is left for future studies. However, the above account lends support for the conjecture that these competent scholars may well have been the first who applied modern economic principles and methods to examine and derive the optimal allocation of complex (natural) resources involving questions of intergenerational distribution. However, they all adhered to the traditional view that land is a distinct production factor which collects all economic rents. A more general (neoclassical) profit maximization formula and its solution would appear a few decades later in Gram (1876).

# 6 SUMMARY OF THE SEPARATE STUDIES

## 6.1 The discovery of the Faustmann formula in natural resource economics (I)

The main objective of the paper is to trace the development of fundamental forest and renewable natural resource economic ideas and principles further back and to link them more closely to the general development of contemporary economic thought than has been done previously. It is shown that John Houghton, a London-based editor, book-reviewer and fellow of the fledgling Royal Society of London, already in 1683 incorporated the opportunity cost of both standing timber and bare land in valid calculations that aimed to compare the economic rationale of forestry with other forms of land use. In this respect, he anticipated Faustmann by well over 150 years. Considering that such explicitly formulated insights related to efficient land allocation and efficient use of forest resources cannot be found in the works of principal economic writers in the seventeenth century, Houghton's contribution is even more remarkable.

Houghton's compatriot, land surveyor and accountant John Richards (1730) has been credited for discovering the celebrated Faustmann formula 120 years earlier than Faustmann. The present study contributes to the current literature by also describing Richards' insights and calculations more thoroughly than before. Richards extended the modern natural resource economic thinking introduced by Houghton by deriving forest land values under various initial states, management regimes and income flows.

An examination of the political, socio-economic and intellectual factors behind these fundamental innovations reveals that the English scholars at the turn of the seventeenth century were able to excel over their counterparts in other countries (particularly Germany) because they took inspiration from the novel economic ideas and practices that transformed the contemporary English commercial and financial markets in an unprecedented way. Their personal interest in economic aspects of forestry, ability to build on established methods of land and other real property valuation, wide intellectual networks and own business activities may explain why they were able to consider forests as a special case of more general intertemporal resource allocation and to apply approaches that in literature have been regarded as of much later origin.

## 6.2 Timber, science and statecraft: the emergence of modern forest economic thought in Germany (II)

The study provides the first systematic analysis of the emergence and early stages of modern forest economic thought in German territorial states. To place this intellectual development in a broader context, the paper first describes the political and economic doctrines and intellectual movements that were active and shaped the ideas and practices related to (sustainable) exploitation of forest resources in the eighteenth-century German territorial states. Then it examines the key factors that promoted interest in natural science, led to the emergence of a more rigorous and systematic treatment of forestry, 'scientific forestry', and eventually prompted the first modern forest economic insights.

The study also shows how the early development of modern forest economic thought in the German territorial states was influenced by cameralistic ideas of prudent resource management, and how attempts to integrate this intellectual tradition with the core premises of neoclassical economics have given rise to some of the most persistent controversies in forest management and planning.

More specifically, the study shows that the idea of the capital nature of forests and associated opportunity costs was introduced in the German academic literature by Georg Heinrich Zincke (1755), one of the leading contemporary cameralists, who was a few years later echoed by his counterpart in forestry, Wilhelm von Moser (1757). It also shows that a high Saxon mining officer Friedrich von Oppel (1760) and Moser's close colleague Hans Dietrich von Zanthier (1764) were perhaps the first German scholars to present numerical calculations of the economic rationale of different forest management regimes.

The study concludes with observations on the prevalence of forest economic reasoning and modelling at the turn of the nineteenth century. It points out that the conventionally celebrated forestry scholars, particularly Hossfeld, König, Faustmann and Pressler, who in the early nineteenth century greatly contributed to the formation of modern forest and natural resource economics, were able to build on the ideas and principles that had been put forward by a group of competent academic cameralists some hundred years earlier and disseminated in the subsequent decades by their forestry colleagues who were inspired by the new mode of scientific thinking and economic rationale.

## 6.3 Faustmann formula before Faustmann in German territorial states (III)

The study extends the current literature by showing that a modern perspective on forest valuation was presented in German tradition nearly 50 years before Faustmann by Julius Nördlinger (1805) and Johann Wilhelm Hossfeld (1805b), perhaps the first “forest economists” who were accustomed to using algebraic notation in their argumentation. Nördlinger proposed that net forest income should be considered interest on forest capital, and that forest value should be calculated based on the “expected future utility” it provides, i.e. on the income it yields over an infinite series of years. Hossfeld’s contribution was even more remarkable, in the sense that he explicitly showed how forest value can be derived under both intermittent and sustained yield management, and how young forests should be appraised accordingly. In this respect, he preceded also those prominent neoclassical economists who, almost a century later, pondered qualitatively similar questions on capital valuation and are conventionally regarded as the founders of modern capital and investment theory.

Early German forest economic literature contains remarks that Gottlob König (1835; 1842) was the first who expounded and utilized the marginal condition that determines optimal timber harvests and, more generally, optimal exploitation of renewable natural resources. The present study provides an explicit description of the marginal method that König applied to determine optimal timber harvests. König’s early accomplishment in outlining the principles of efficient forest management should be evaluated against the fact that the classical article by Faustmann (1849b) did not contain an explicit solution to the optimal rotation problem, and even Pressler’s (1860) landmark paper in which he derived his celebrated “indicator percent” (*Weiserprozent*), relied on an incremental analysis similar to the one König used.

The study also elucidates the close intellectual and professional connections among the early scholars of German scientific forestry and its evolving branch of forest economics. Special attention is directed to possible ways through which the commercial, financial and intellectual development in other countries may have stimulated and supported the rise of a more advanced forest economic reasoning and calculations in German territorial states. One intriguing finding is that Hossfeld and other contemporary German forestry scholars may have significantly benefited from the flow of ideas and material from other countries, especially England, where a remarkably modern financial system had already been functioning from the 1690s. Finally, the study describes how the fundamental principles of modern forest resource economics, expounded by Hossfeld and König, made their way to Faustmann’s and Pressler’s writings where they were presented in a more comprehensive and analytical form.

## 6.4 An early contribution of Martin Faustmann to natural resource economics (IV)

The study contributes to the current literature by directing attention to an article which presents a modern economics approach to the valuation and use of renewable natural resources earlier than its traditional time slot in the development of economic thought. The article under nom de plume F., published in August 1849, is a landmark in the capital valuation of forests and other renewable natural resources because it appears to contain the first comprehensive and explicit description of the valuation principles in accord with modern capital and investment theory.

In contrast to Faustmann's subsequent classical article, published only few months later in the same German forestry journal, the article by F. also shows how the optimal cutting age of standing timber can be determined analytically using differential calculus and demonstrates how the valuation method adopted can be used to solve several other key questions related to efficient forest management and land use. The numerical examples deal also with forests under multiple stands although in this connection forest values are calculated assuming that it is optimal to convert the initial forest to an even age-class structure. Summing up the discounted net cash flow from the conversion period and from the 'normal forest' era to infinity yields the net present value of the forest. To add perspective, similar valuation method is still used conventionally in the forest economics literature. Several facts suggest that the article was actually written by Faustmann and that it was his first contribution to discovering the principles that are still, 165 years later, at the heart of forest economics research.

### 6.5 Does the Faustmann rotation apply to fully regulated forests? (V)

Forest economics literature contains two lines of research in which the Faustmann rotation is taken to be invalid for continuous harvesting, i.e. for normal or fully regulated forests. As an alternative, "a marginal model for divisible capital", originating from Duerr and Bond (1952) and Bond and Guttenberg (1953) and Duerr (1960), and advocated more recently by Duerr (1990), Oderwald and Duerr (1990) and Kant (2013, 2), has been proposed and applied. A more recent subgroup of studies originates from Comolli (1981) who formulated a "neoclassical interpretation" of the optimum rotation problem under continuous harvesting. His "regular model for timber production" has been applied extensively as a basis for theoretical generalizations and for empirical computations (e.g. Yin and Newman 1996; 1997; 1999; Yin 1997; 2001; Yin et al. 1998; Yin and Sedjo 2001).

The main argument behind the alternative models has been that the Faustmann approach is designed for stand-level modelling but is inherently flawed and unable to address various multiple-stand, forest-level and regional-level issues. This argumentation has caused confusion in forest economics: some have taken a stand that the claim may be valid while others have pointed out that in an unconstrained market it is difficult to build a theoretical defense for the use of such alternative models. From a historical perspective, the advocacy of the alternative models very much coincides with foresters' traditional desire to circumvent long-term discounting and associated perception that under sustainable yield forestry the Faustmann approach loses its relevance because of some interdependencies between forest stands.

In this paper, it is shown analytically that the "marginal model for divisible forest capital" by Oderwald and Duerr is economically unwarranted. The "regular model for timber production" introduced by Comolli differs in some respects from the Oderwald-Duerr model but it is shown that, despite these differences, the optimal condition for it collapses to exactly the same first-order condition as in the Oderwald-Duerr formulation. Thus both models yield the same unoptimally short rotation. Numerical examples suggest that the magnitude of error may not be minor and that the Oderwald-Duerr-Comolli model may give misleading signals on the profitability of forestry. It is also shown that the error lies in the specification of the value of the normal forest: young stands are valued by their immediate sale value. When this error is corrected and the economically valid continuous harvesting model is formulated, the Faustmann rotation proves to be optimal also for a fully regulated forest.

# 7 DISCUSSION

The purpose of this study was to trace the emergence and development of the fundamental ideas and principles in forest and renewable natural resource economics further back in history than has been done previously. The second aim was to provide a framework that allows one to evaluate this intellectual process in a broader context, particularly its connections with the concurrent socio-economic conditions, political ambitions and intellectual movements. The third objective was to examine the origins and underlying motivations of some of the most persistent controversies that have circled forest management and planning at different theoretical and operational levels until present days.

To avoid the myopic and narrow though common perception that the history of natural resource economic thinking emerged with the revelations of French physiocrats and English political economists in the latter part of the eighteenth century, the study first provided a description of the early development of commercial arithmetic and land valuation. Then it showed that although compound interest and relatively sophisticated land and other property valuation techniques had been around for centuries, it took quite long until they were applied in a coherent manner to forestland and standing timber stocks.

Sir William Petty (1672–1673) may have been the first who treated planted trees as a long-term financial investment; John Houghton (1683; 1701) the first who explicitly recognized the role of opportunity cost of both standing timber and bare land, as well as compared the present values obtainable from forestry to those from other forms of land use with valid economic calculations; and John Richards (1730) the first who correctly determined the value of a forest under both intermittent and sustained yield management. These findings are novel except for Richards’ accomplishment which has been recognized in the literature (Scorgie 1996). However, the present study placed Richards’ contribution in proper context by showing that his merit lies in the fact that he successfully applied the contemporary land and capital valuation method to concern renewable natural resources (forests) which generate perpetual periodic series of net income at intervals of considerable time and often involve complex capital vintage structures.

Similar sophistication in forest economic thinking developed considerably later in German territorial states. Zincke (1755) seems to have been the first in the German tradition to put forward the idea of the capital nature of forests and associated opportunity costs, though only in the context of sustained yield forestry. Oppel (1760), Zanthier (1764) and di Paprica (1789) presented some innovative calculations on the profitability of different forest management regimes but their efforts clearly lagged behind in economic insight and validity of those by Houghton and Richards decades earlier.

Burgsdorf’s (1796) extensive textbook is an important landmark in the early development of German forest economic thought. It contains solid calculations on the capital value of sustained-yield forests as well as relatively modern discussion of the rationale and level of risk-adjusted interest rate in forestry. As described in Moog (2012) and Abel et al. (2015), the ideas and principles presented by Burgsdorf were reiterated and developed further at the turn of the century. A noteworthy discussion of forest valuation and risk-adjusted interest rates in forestry can be found, for example, in the lesser-known works of von Jordan (1800), Krause (1812) and Kröncke (1813). Nördlinger (1805) contributed to this line of economic thinking by articulating that net forest income should be considered interest on forest capital and that forest value should be calculated based on the "expected future utility" it provides, i.e. on the income it yields over an infinite series of years.

However, there seems to be a relatively strong case that Johann Wilhelm Hossfeld (1805b) was the first in the German tradition who explicitly showed how forest value can be derived under both intermittent and sustained yield management. His particular merit is that he also demonstrated how young forests should be appraised accordingly. The interesting point here is that the persistent claim of the invalidity of the Faustmann rotation for continuous harvesting, i.e. sustained yield forestry, has motivated some 150 years later the construction and use of two alternative economic models of forestry ("marginal model for divisible capital" and "regular profit model") which are based on an unwarranted specification for the value of young forests.

A young forest official Carl Montanus (1807), at the time assigned in the Black Forest region, may have been the first to derive forest values by summing two components: the present value of standing timber (discounted from the end of the first rotation period) and the present value of all succeeding crops (*Bodenwerth*). However, the bare land value in his calculations was exogenous. An anonymous (1807) writer with nom de plume "E." took these ideas further by showing how bare land values can be derived from the perpetual periodic series of gross timber income. The chief purpose of these writers was to demonstrate how small forest holdings with unequal forest age-class structure and timber income flows could be objectively valued in purchase transactions.[74]

A few years later, Hossfeld's close colleague and another autodidact König (1813) also presented calculations that correspond to the Faustmann formula, yet without accounting for the recurring regeneration costs. The fact that König considered regeneration costs only once, in the beginning of the first rotation period, while Faustmann used a series of regeneration costs and discounted them, may have reflected König's orientation towards natural regeneration, which was commonly used with pine at the time. This notion is supported by the fact that König did correctly account for the capital value of perpetual administration costs.

In his subsequent works König (1935; 1942) went on to introduce the concept of "value increment percent" (*Werthzunahme-Prozent*) and its more sophisticated variant "net value increment percent" (*bodenfreie Werthzunahme-Prozent, reine Werthzunahme-Prozent*). The latter concept is similar to Pressler's "indicator percent" (*Weiserprozent*) and thus also bears close resemblance to the celebrated Faustmann condition. Faustmann's and Pressler's seminal contribution a few decades later was that they presented these fundamental forest economic principles in a more comprehensive and analytical form and provided a modern economic framework for using them in forest management. Hossfeld's achievement is

[74] "E." criticized Montanus for relying on exogenous ('arbitrary') bare land values. For the ensuing debate between them, see Montanus (1808) and Anonymous (1808).

novel in the literature, whereas Nördlinger's and König's accomplishments have not received due credit in modern forest economic literature.

The German development was by no means linear; it can instead be characterized as a process in which a collection of occasional and dispersed insights of the role of capital and interest rate in forestry, gradually, during a time span of almost a hundred years, transformed into a more coherent understanding of the economic aspects of forest management and land allocation. In this respect, it greatly diverted from previous development in England where the corresponding discussion – spurred by the more liberal political environment and accompanying transition toward modern commercial and financial markets – led relatively early to the articulation of fundamental principles of forest and natural resource economics consistent with modern capital and investment theory.

The distinctly different developmental paths in England and German territorial states are illustrated in Figure 3. A more detailed account of the landmark contributions in the development of forest economic thought and of their originators is presented in Appendices 3 and 4.

The common intellectual roots of forest and renewable natural resource economics and modern capital and investment theory is an issue that surfaces in this dissertation. Petty and Houghton may have been the first to recognize the capital-theoretic nature of forest stands, but it is difficult to establish conclusively to what extent they and the first German 'forest economists' (Hossfeld, König, Faustmann, Pressler), a hundred plus years later, featured as forerunners of more general capital and investment theory. Modern capital valuation methods had been around for a long time prior to Richards (1730), and in a similar way Houghton (1683; 1701) could rely on established techniques in valuing land and leases and in comparing present and future values of investments.

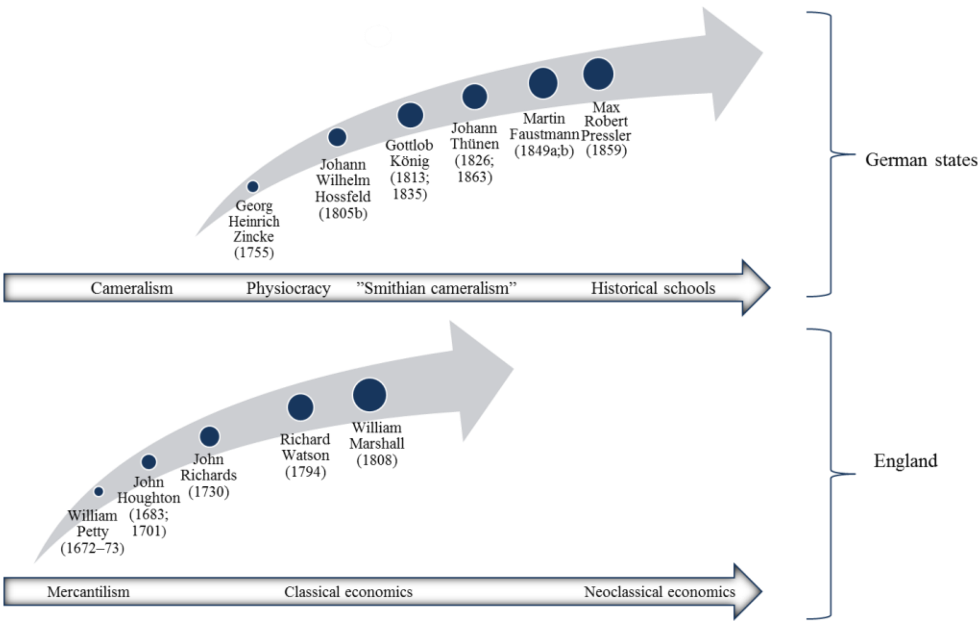


**Figure 3**. Developmental path of the early forest economic thought in England and German states.

Considering the sophistication of financial calculations in Europe at least since Pisano’s encyclopedic work *Liber abaci* (1202), it appears that the principles underlying the Faustmann formula could have been applied centuries prior to Richards. However, current evidence suggests that Richards may indeed have been the first to use them to derive forest value under both sustained and intermittent forestry.

The Faustmann model may be the oldest *formal description* of natural resource use that is still considered to be theoretically valid (cf. Tahvonen and Salo 1999), but the recurring claim in forest economic literature that Faustmann and Pressler produced a capital theory that outplayed and was developed even earlier than its cousins within the economic discipline (cf. Löfgren 1990; 1995; 2012) appears more dubious. Considering the long traditions in land and property valuation and the somewhat elusive origins of the marginal method, a more tenable conclusion might be that the early English and German scholars examining modern economic aspects of forest resource use and land allocation seem to qualify as precursors of applying principles of modern capital theory and marginal analysis to *complex* (natural) resources.

Another noteworthy merit of the early German forest scholars is that they made some pioneering efforts to integrate economics and biological processes when examining stand- and forest-level timber management. In his less-known work Faustmann (1849a), for example, made an attempt to derive the optimal time to harvest a forest stand by specifying a stylized forest value growth function and applying differential calculus to solve the related maximization problem. Similar modelling activities in more rigorous form began to gain ground in modern bioeconomics, i.e. the theory of economic exploitation of living resources, some hundred years later (see e.g. Crocker 1999; Pearce 2002; Quinn 2003; Sandmo 2015).

*Avenues for further research*

There are several issues that call for further research. Perhaps the most intriguing questions concern the English development: Did Sir William Petty and John Houghton have some predecessors? How William Marshall came to realize the underlying marginal principle of the Faustmann condition?

Hossfeld’s possible connection with the concurrent English business life and its professionals is another fascinating issue. To what extent was he able to draw inspiration from the remarkably modern English commercial, financial and agricultural development while he was lecturing at the local English business school in Eisenach, Thuringia, from 1791 to 1798?

The leading German agriculturalists of the time maintained close connections with their English colleagues. The prime example is Albrecht Thaer who in 1780 was appointed to the Royal Agricultural Society Electoral in Hanover and four years later was elected to the Royal Society of London. Thus he became acquainted with the leading English agriculturalists of the time, including Arthur Young and William Marshall. An interesting question remains whether Thaer, through his international network, became also informed of the works of Petty, Houghton, Richards and Watson and, if so, whether he passed this information to his students, among them young Johann Heinrich von Thünen. After studying under Thaer at Celle, Thünen in 1803 went to study philosophy, biology, economics and languages at the University of Göttingen which functioned as a gateway for the influx of British political and social thought (Biskup 2007, 128).[75]

Being one of the leading German academic cameralists, Zincke almost certainly was aware of the rapid economic development and the rise of remarkably modern financial markets in England. Although the textbooks by Stisser (1735; 1737; 1746), from which Zincke apparently learned forestry, do not contain any modern forest economic insights, it seems plausible that similar ideas of forest valuation had been around also in the German tradition before Zincke, especially considering that sophisticated German *Rechenbücher* had been available from the sixteenth century when many large South German merchant-banking houses became more intimately involved in the rapidly expanding *rente* and other private and public credit markets (see Kindleberger 1985; Munro 2003). As described in sections 3.3 and 3.4, it was the rente contracts that provided a basis for those sophisticated land and other real property valuation methods that conform to modern capital valuation.

Another interesting question left for future studies is to what extent König, Faustmann and Pressler were influenced by the thriving German tradition in economics around the mid-nineteenth century. This tradition was dominated by Karl Heinrich Rau and Friedrich Hermann but engaged also many other prominent German economists (e.g. Gossen, Mangoldt, Roscher), whose ideas and works went on to inspire some towering figures of early modern economics, e.g. Carl Menger, Eugene von Böhm-Bawerk and Alfred Marshall (see e.g. Streissler 1990a). This issue is of particular interest considering that long before England or United States had developed a full-scale academic establishment or established academic teaching in economics, economics had become an academic profession in German states. However, it was considered to be a threefold subject: economic theory, economic policy (originally called "police", i.e. administrative law in matters economic) and public finance (treasury). This tripartition involved an uneasy compromise between the strong cameralistic heritage with high ambitions to control and regulate economy and classical political economics with more *laissez-faire* type of thinking (Streissler 1990b). The resulting peculiar hybrid doctrine, sometimes called as 'Smithian cameralism' (e.g. Schumpeter 1954, 501) established the skeptical and critical attitude toward economic theory that would be characteristic of much German economic thought in the nineteenth and twentieth centuries (Betz 1988; Silverman 1990). This orientation is readily discernible also in the classical German forestry scholarship whose traditions dominated the forestry profession and forest science until the second World War and in some respects even beyond.

Another unresolved issue concerns the possible intellectual connections between the first German forest economists (Hossfeld, König, Faustmann, Pressler) and Thünen. It has been suggested that *Der isolierte Staat* was not widely read in Thünen's day. The reasoning is quite convincing: Thünen was a liberal in an era when liberalism was anathema in Germany; he was a theorist in a country dominated by antitheoretical bias of the historical school; he lacked academic status and even a university degree; he made constant use of

---

[75] Thaer was educated and spend much of his early professional career in the Electorate of Hanover which was ruled 1714–1837 by the British monarchs. The political union promoted close administrative, business and scientific connections between England and northern Germany. On the opening pages of his extensive treatise *The Principles of Agriculture* Thaer ([1809–1812] 1852, 1–34) expounded the connection between landed capital and rents, and articulated that the various forms of capital tied in agricultural pursuits have opportunity costs. The work which initially made Thaer (1798–1804) famous was his three volume compilation *Introduction to English Agriculture*, perhaps the most explicit contemporary evidence of the diffusion of modern ideas of farm management from England to northern Germany.

algebra and differential calculus; his books appeared in several instalments over a 37-year period; and, last, he wrote somewhat cryptically and obscurely (Dickinson 1969; Blaug 1990, 122). On the other hand, his book (first volume in 1826) received complimentary reviews and he became an acknowledged agriculturalist at least in the Rostock region in northern Germany.

The present study concentrated mostly on how economic ideas of forest and renewable natural resource valuation and use developed through time in England and German territorial states, but similar early insights might also be found in Holland and northern France due to the sophistication of local financial and commercial markets already from the late sixteenth century. Such insights could perhaps also be discovered at some later points of time in Switzerland, Italy and the Nordic countries judging from the remarks by Zschokke (1804, 232), Gioja (1817, 316–318) and Böcker (1829, 34) respectively. All these writers articulated the capital nature of forests and its implications to forest management. An equally interesting question left for future studies is whether Ohlin (1921) indeed was the first who specified the Faustmann formula in continuous time and went on to analytically derive the corresponding Faustmann condition, and whether Gram (1876) should be credited for similar achievements in the framework of profit maximization.

# REFERENCES

Abel, P., Moog, M., Riesen, S. van. (2015). Beiträge forstlicher Autoren zur Ideengeschichte der Unternehmensbewertung. Betriebswirtschaftliche Forschung und Praxis 67: 227–239.

Alchian A.A., Allen, W.R. (1972). University Economics: Elements of Inquiry. 3rd edition. Wadsworth Publ., Belmont, CA.

Alchian A.A., Allen, W.R. (1983). Exchange & Production: Competition, Coordination & Control. 3rd edition. Wadsworth Publ., Belmont, CA.

Andersen, P. (1983). "On rent of fishing grounds". A Translation of Jens Warming's 1911 article with an introduction. History of Political Economy 15: 391–396. http://dx.doi.org/10.1215/00182702-15-3-391

Anonymous. (1807). Bemerkungen zu dem Aufsatze in Nro. 35 dieses Journals: über die Abschätzung kleiner Stücke Hochwaldungen, die zu verkaufen sind. Journal für das Forst-, Jagd- und Fischereiwesen Nro 44: 689–695.

Anonymous. (1808). Antwort auf die Bemerkungen in Nr. 8, seite 124 dieses Journals vom Jahr 1808. Journal für das Forst-, Jagd- und Fischereiwesen Nro 8: 201–205.

Apian, P. (1527). Eyn Newe und wohlgegründte Unterweysung aller Kauffmanns-Rechnung in dreyen Büchern. Ingolstadt.

Appleby, J.O. (1978). Economic Thought and Ideology in Seventeenth-Century England. Princeton University Press, Princeton, NJ.

Augello, M.M., Guidi, M.E.L. (eds.) (2001). The Spread of Political Economy and the Professionalisation of Economists. Routledge Studies in the History of Economics. Routledge, London.

Austen, R. (1653). A Treatise of Fruit-Trees. Oxford. (2nd improved edition in 1656)

Backhouse, R.E. (1985). A History of Modern Economic Analysis. Basil Blackwell, Oxford.

Bailey, M. (1989). The Concept of the Margin in the Medieval English Economy. Economic History Review 42: 1–17. http://dx.doi.org/10.2307/2597043

Baranov, F.I. (1918). On the question of the biological basis of fisheries. Nauchnge Issledovaniya Ikhtiologicheskii Instituta Izvestiya 1: 81–128.

Barber, W.J. (1993). The Fortunes of Political Economy in an Environment of Academic Conservatism: Yale University. In: Barber, W.J. (ed.) Economists and Higher Learning in the Nineteenth Century. Transaction Publishers, New Brunswick, NJ. p. 132–168.

Barber, W.J. (2001). Economists and professional organisations in pre-Word War I America. In: Augello, M.M., Guidi, M.E.L. (eds.) The Spread of Political Economy and the Professionalisation of Economists. Routledge Studies in the History of Economics. Routledge, London. p. 216–232.

Barber, W.J. (2003). American Economics to 1900. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 231–245. http://dx.doi.org/10.1002/9780470999059.ch15

Barbon, N. [1690] 1905. A Discourse of Trade. Reprint in 1905, The Lord Baltimore Press, Baltimore, MD.

Bath, B.H.S. van. (1963). The Agrarian History of Western Europe A.D. 500–1850. Edward Arnold, London.

Bendall, S. (ed.) (1997). Dictionary of Land Surveyors and Local Map-makers of Great Britain and Ireland 1530–1850. 2nd edition. The British Library, London.

Bernhardt, A. (1872). Geschichte des Waldeigenthums, der Waldwirthschaft und Forstwissenschaft in Deutschland. Erster Band. Springer, Berlin.
Bernhardt, A. (1874). Geschichte des Waldeigenthums, der Waldwirthschaft und Forstwissenschaft in Deutschland. Zweiter Band. Springer, Berlin.
Bernhardt, A. (1875). Geschichte des Waldeigenthums, der Waldwirthschaft und Forstwissenschaft in Deutschland. Dritter Band. Springer, Berlin. http://dx.doi.org/10.1007/978-3-662-32960-3
Betz, H.K. (1988). How does the German Historical School fit? History of Political Economy 20: 409–430. http://dx.doi.org/10.1215/00182702-20-3-409
Biddle, J.E. (2003). Research Styles in the History of Economic Thought. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 1–8. http://dx.doi.org/10.1002/9780470999059.ch1
Birrell, J.R. (1980). The medieval English forest. Journal of Forest History 24: 78–85. http://dx.doi.org/10.2307/4004501
Birrell, J. (1987). Common rights in the medieval forest: disputes and conflicts in the thirteenth century. Past and Present 117: 22–49. http://dx.doi.org/10.1093/past/117.1.22
Biskup, T. (2007). The university of Göttingen and the Personal Union, 1737–1837. In: Simms, B., Riotte, T. (eds.) The Hannoverian Dimension in British History, 1714–1837. Cambridge University Press, Cambridge. p. 128–160.
Blaug, M. (1968). Economic Theory in Retrospect. Revised edition. Irwin, Homewood, Ill.
Blaug, M. (1985). Economic Theory in Retrospect. 4th edition. Cambridge University Press, Cambridge.
Blaug, M. (1986). Was There a Marginal Revolution? In: Blaug, M. (ed.) Economic History and the History of Economics. Harvester Wheatsheaf, Brighton. p. 209–218. Reprint of the original article in 1972, History of Political Economy 4: 269–280.
Blaug, M. (1990). The economics of Johann von Thünen. In: Blaug, M. (ed.) Economic Theories, True or False? Edward Elgar, Aldershot. p. 121–143.
Blaug, M. (1997). Economic Theory in Retrospect. 5th edition. Cambridge University Press, Cambridge.
Blith, W. (1649). The English Improver. London.
Blith, W. (1652). The English Improver Improved; or the Survey of Husbandry Surveyed. 3rd revised edition. London.
Bond, W.E., Guttenberg, S. (1953). Methods of evaluating alternatives in timber or forage management. In: Duerr, W.A., Vaux, H.J. (eds.) Research in the economics of forestry. Waverly Press, Baltimore, MD. p. 225–233.
Boulding, K.E. (1935). The theory of single investment. Quarterly Journal of Economics 49: 475–494. http://dx.doi.org/10.2307/1883864
Braudel, F. (1972). The Mediterranean and the Mediterranean World in the Age of Philip II. 2 vols. Harper & Row, New York.
Braudel, F. (1981–1984). Civilization and Capitalism, 15th–18th Century. 3 vols. William Collins, London.
Brazee, R.J. (2001). The Faustmann Formula: Fundamental to Forest Economics 150 Years after Publication. Forest Science 47: 441–442.
Burgsdorf, F.A.L. von. (1796). Forsthandbuch – Allgemeiner theoretisch-praktischer Lehrbegriff der höhern Forstwissenschaften. Zweiter Theil. Selbsverlag, Berlin.

Böcker, C.C. [1829] 1929. Om skogars skötsel i Norden [On forest management in the Nordic countries]. Första delen. Hjelt, Åbo. Reprint with an English introduction by E.A.M. Hagfors, Silva Fennica 13: 1–88. (In Swedish)

Böhm-Bawerk, E. von. [1888] 1889. Positiven Theorie des Capitales. English translation in 1889: The Positive Theory of Capital. MacMillan, London.

Böhm-Bawerk, E. von. [1890] (1970). Capital and Interest: A Critical History of Economic Theory. Reprint of the English translation, Kelley, New York.

Böhm-Bawerk, E. von. (1907). Capital and Interest Once More: II: A Relapse to the Productivity Theory. Quarterly Journal of Economics 21: 247–282. http://dx.doi.org/10.2307/1883433

Cardano, G. [1545] 1993. Artis Magnæ, Sive de Regulis Algebraicis Liber Unus. Reprinted in 1993 as The Rules of Algebra (Ars Magna). Dover Publications, Mineola, NY.

Cardoso, J.L., Psalidopoulos, M. (eds.) (2016). The German Historical School and European Economic Thought. Routledge Studies in the History of Economics. Routledge, New York.

Carlowitz, H.C. von. (1713). Sylvicultura oeconomica, oder hausswirthliche Nachricht und Naturmässige Anweisung zur wilden Baum-Zucht. Braun, Leipzig.

Chambers, R. (1612). An Olde Thrift Newly Revived. Wherein is Declared the Manner of Planting, Preserving, and Husbanding yong Trees of diuers kindes for Timber and Fuel. London.

Child, J. [1668] 1959. Brief Observations concerning Trade and Interest of Money. In: Letwin, W. (ed.) Sir Josiah Child, Merchant Economist. Harvard University Press, Cambridge, MA. p. 40–58.

Child, J. [1690] 1693. A Discourse about Trade. Reprinted in 1693 as A New Discourse of Trade. (4th edition in 1745)

Chuquet, N. (1484). Le Triparty en la Science des Nombres [The Science of Numbers in Three Parts].

Clark, C.W. (1990). Mathematical Bioeconomics. The Optimal Management of Renewable Resource. 2nd edition. Wiley, New York.

Clark, C.W. (2011). Foreword. In: Zhang, D., Pearse, P.H., Forest Economics. UBC Press, Vancouver. p. xv–xvi.

Clark, C.W., Munro, G.R. (1975). The economics of fishing and modern capital theory: a simplified approach. Journal of Environmental Economics and Management 2: 92–106. http://dx.doi.org/10.1016/0095-0696(75)90002-9

Clark, J.B. (1899). The Distribution of Wealth: A Theory of Wages, Interest, and Profits. Macmillan, New York.

Clay, C. (1974). The price of freehold land in the later seventeenth and eighteenth centuries. The Economic History Review 28: 173–189. http://dx.doi.org/10.2307/2593338

Clay, C. (1980). The greed of whig bishops?: Church landlords and their lessees 1660–1760. Past and Present 87: 128–157. http://dx.doi.org/10.1093/past/87.1.128

Clay, C. (1981). Lifeleasehold in the western counties of England 1650–1750. Agricultural History Review 29: 83–96.

Clay, T. (1618). Briefe, Easie, and Necessary Tables, of Interest and Rents Forborne as Also, for the Valuation of Leases, Annuities, and Purchases, Either in Present, etc. London. (3rd enlarged edition in 1624)

Cohen, A. (2003). The Hayek/Kaldor capital controversy: The irrelevance of roundaboutness, or purging processes of time? History of Political Economy 35: 469–490.

http://dx.doi.org/10.1215/00182702-35-3-469
Cohen, A. (2008). The mythology of capital or of static equilibrium? The Böhm-Bawerk/Clark controversy. Journal of the History of Economic Thought 30: 151–171. http://dx.doi.org/10.1017/s1042771608000161
Colson, W. (1612). A general tresury, a perpetual repertory, or, A common councel-place of accounts for all countries in Christendome. London.
Comolli, P.M. (1981). Principles and policy in forestry economics. Bell Journal of Economics 12: 300–309. http://dx.doi.org/10.2307/3003526
Condorcet, N. de. [1776] 1847–1849. Réflexions sur le commerce des blés. In: O'Connor, A., Arago, M.F. (eds.) Oeuvres de Condorcet. Firmin-Didot, Paris.
Crescenzi, P. de [1304–1309] 1471. Ruralia commoda. Published as a printed book in 1471. Augsburg. (In Latin)
Crocker, T.D. (1999). A short history of environmental and resource economics. In: Bergh, J.C.J.M. van den (ed.) Handbook of Environmental and Resource Economics. Edward Elgar, Cheltenham. p. 32–45. http://dx.doi.org/10.4337/9781843768586.00011
Culpeper, T. Sr. [1621] 1974. A Tract Against Usurie. Reprint in 1974, Theatrum Orbis Terrarum, Amsterdam.
Culpeper, T. Jr. (1668). A Discourse Shewing the Many Advantages that Will Accrue to this Kingdom by the Abatement of Usury. Thomas Leach, London.
Dardi of Pisa. [1344] 2001. Aliabraa argibra. A later version (c. 1470), edited by R. Franci, published in 2001. Quaderni del Centro Studi della Matematica Medioevale, Università di Siena, Siena.
Davis, N.Z. (1960). Sixteenth-century French arithmetics on the business life. Journal of the History of Ideas 21: 18–48. http://dx.doi.org/10.2307/2707997
Deegen, P., Seegers, C. (2011). Establishing Sustainability Theory within Classical Forest Science: The Role of Cameralism and Classical Political Economy. In: Backhaus, J.G. (ed.) Physiocracy, Antiphysiocracy and Pfeiffer. The European Heritage in Economics and Social Sciences, Vol. 10. Springer, New York. p. 155–168. http://dx.doi.org/10.1007/978-1-4419-7497-6_11
Deß Fürstenthumbs Neuburg, Erneuerte Forst und Holtz-Ordnung. (1690). II Theil, 14. Artickel. Johann Feuchtner, Neuburg.
Devarajan, S., Fisher, A.C. (1981). Hotelling's "Economics of Exhaustible Resources" fifty years later. Journal of Economic Literature 19: 65–73.
Dickinson, H.D. (1969). Von Thünen's economics. The Economic Journal 79: 894–902. http://dx.doi.org/10.2307/2229798
Dickson, H. (1953). Forest rotation – a contribution to the theory of the optimum investment period. Weltwirtschaftliches Archiv 70: 205–240.
Dickson, H. (1956). Ekonomiska principer bakom Svensk skogsvårdslagstiftning [Economic Principles behind Swedish Forestry Legislation]. Svenska skogsvårdsföreningens Förlag, Stockholm. (In Swedish)
Dijksterhuis, E.J. (1955). The principal works of Simon Stevin. Vol. I. Swets & Seitlinger, Amsterdam.
Divine, T.F. (1959). Interest: An Historical and Analytical Study in Economics and Modern Ethics. Marguette University Press, Milwaukee, WI.
Duerr, W.A. (1960). Fundamentals of forestry economics. McGraw-Hill, New York.
Duerr, W.A. (1990). Introduction to forest resource economics. McGraw-Hill International Editions, New York.

Duerr, W.A., Bond, W.E. (1952). Optimum stocking of a selection forest. Journal of Forestry 50: 12–16.
Duerr, W.A., Teeguarden, D.E., Christiansen, N.B., Guttenberg, S. (1979). Forest Resource Management: Decision-Making Principles and Cases. Saunders, Philadelphia.
Ekelund, R.B. Jr., Hébert, R.F. (1976). Dupuit and marginal utility: context of the discovery. History of Political Economy 8: 266–273. http://dx.doi.org/10.1215/00182702-8-2-266
Ekelund, R.B. Jr., Hébert, R.F. (1978). French engineers, welfare economics, and public finance in the nineteenth century. History of Political Economy 10: 636–668. http://dx.doi.org/10.1215/00182702-10-4-636
Ekelund, R.B. Jr., Hébert, R.F. (2014). A History of Economic Theory and Method. 6th edition. Waveland Press, Long Grove, Ill.
Ely, R.T. (1918). Conservation and Economic Theory. In: Ely, R.T., Hess, R.H., Leth, C.K., Carver, T.N. (eds.) The Foundations of National Prosperity. Macmillan, New York. p. 3–91.
Emmett, R.B. (2003). Exegesis, Hermeneutics, and Interpretation. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 523–537. http://dx.doi.org/10.1002/9780470999059.ch35
Endres, M. (1894). Lehrbuch der Waldwertrechnung und Forststatik. Springer, Berlin.
Endres, M. (1911). Lehrbuch der Waldwertrechnung und Forststatik. 2. vollständig neu bearbeitete Auflage. Springer, Berlin. (4th edition in 1923)
Endres, M. (1922). Handbuch der Forstpolitik mit besonderer Berücksichtigung der Gesetzgebung und Statistik. 2. Auflage. Springer, Berlin.
Ericsson, B. (1896). Näkökohtia metsämaan arvon laskemisessa [On forest valuation]. Finnish Forestry Association, Helsinki. (In Finnish)
Ericsson, B. (1903). Oppi- ja käsikirja metsätalouden järjestelyssä. Ensimmäinen osa. Metsänarvioiminen [Forest mensuration]. Weilin & Göös, Helsinki. (In Finnish)
Ericsson, B. (1906). Oppi- ja käsikirja metsätalouden järjestelyssä. Toinen osa. Metsänjako-oppi [Forest regulation]. Weilin & Göös, Helsinki. (In Finnish)
Evans, A. (1936). Francesco Balducci Pegalotti, La pratica della mercatura. English translation. The Medieval Academy of America, Cambridge, MA.
Evelyn, J. (1664). Sylva, or a Discourse of Forest-Trees. Martyn & Allestry, London. (Further editions in 1670, 1679, 1706 and 1729)
FAO (2010). Global Forest Resources Assessment 2010. Main report. FAO Forestry Paper 163. Food and Agriculture Organization of the United Nations, Rome.
Faulhaber, G.R., Baumol, W. (1988). Economists as innovators: Practical products of theoretical research. Journal of Economic Literature 26: 577–600.
Faustmann, M. (1849a). Anlösung einer Aufgabe der Waldwerthrechnung. Allgemeine Forst- und Jagd-Zeitung 15: 285–299.
Faustmann, M. (1849b). Berechnung des Wertes welchen Waldboden, sowie noch nicht haubare Holzbestände für die Waldwirtschaft besitzen. Allgemeine Forst- und Jagd-Zeitung 15: 441–455. Reprint of the English translation in 1995: Calculation of the value which forest land and immature stands possess for forestry. Journal of Forest Economics 1: 7–44.
Fernow, B.E. (1902). Economics of Forestry. A Reference Book for Students of Political Economy and Professional and Lay Students of Forestry. Thomas Crowell, New York.
Fetter, F.A. [1928] 2007. Economic Principles. Part 1. Elements of Value and Price. Reprint in 2007, The Ludwig von Mises Institute, Auburn, AL.
Fisher, I. (1906). The Nature of Capital and Income. Macmillan, New York.

Fisher, I. (1907). The Rate of Interest. Its Nature, Determination and Relation to Economic Phenomena. Macmillan, New York.

Fisher, I. (1930). The Theory of Interest. Macmillan, New York.

Fitzherbert, A. [1534] 1882. The Boke of Husbandry. Reprinted in 1882 as The Book of Husbandry. London.

Franke, K.H. (2001). Verlaufsformen der Entwicklung des Rechenbuchs der deutschen Volksschule, aufgezeigt an ausgewählten Beispielen des Rechenbuchs aus dem 18., 19. und 20. Jahrhundert. Dissertation, Friedrich-Alexander-Universität Erlangen-Nürnberg.

Franklin, T.B. (1948). A History of Agriculture. Bell & Sons, London.

Fussell, G.E. [1947] 2003. The Old English Farming Books from Fitzherbert to Tull 1523 to 1730. Reprint in 2003, Read Books.

Gaffney, M.M. (1957). Concepts of financial maturity of timber and other assets. Department of Agricultural Economics, Information Series No. 62. North Carolina State College, Raleigh, NC.

Gaffney, M.M. (2008). Keeping land in capital theory. Ricardo, Faustmann, Wicksell, and George. American Journal of Economics and Sociology 67: 119–141. http://dx.doi.org/10.1111/j.1536-7150.2007.00562.x

Gane, M. (1968). Martin Faustmann and the evolution of discounted cash flow. Commonwealth Forestry Institute Paper 42, Oxford University.

Garrison, R.W. (1990). Austrian capital theory: the early controversies. In: Caldwell, B.J. (ed.) Carl Menger and his legacy in economics. History of Political Economy, annual supplement to volume 22. Duke University Press, Durham and London. p. 133–154.

Geisst, C.R. (2013). Beggar Thy Neighbor: A History of Usury and Debt. University of Pensylvania Press, Philadelphia. http://dx.doi.org/10.9783/9780812207507

Getz, W.M., Haight, R.G. (1989). Population Harvesting: Demographic Models of Fish, Forest, and Animal Resources. Yale University Press, New Haven, CT.

Gioja, M. (1817). Nuovo prospetto delle scienze economiche. Volume 6. Pirotta, Milano.

Goetzmann, W.N. (2005). Fibonacci and the Financial Revolution. In: Goetzmann, W.N., Rouwenhorst, K.G. (eds.) The Origins of Value: The Financial Innovations that Created Modern Capital Markets. Oxford University Press, Oxford. p. 123–143.

Goetzmann, W.N., Rouwenhorst, K.G. (2005a). Introduction: Financial Innovations in History. In: Goetzmann, W.N., Rouwenhorst, K.G. (eds.) The Origins of Value: The Financial Innovations that Created Modern Capital Markets. Oxford University Press, Oxford. p. 3–16.

Goetzmann, W.N., Rouwenhorst, K.G. (2005b). Perpetuities in the Stream of History. In: Goetzmann, W.N., Rouwenhorst, K.G. (eds.) The Origins of Value: The Financial Innovations that Created Modern Capital Markets. Oxford University Press, Oxford. p. 177–188.

Gollier, C., Hammitt, J.K. (2014). The long-run discount rate controversy. Annual Review of Resource Economics 6: 273–295. http://dx.doi.org/10.1146/annurev-resource-100913-012516

Gómez-Baggethun, E., de Groot, R., Lomas, P.L., Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. Ecological Economics 69: 1209–1218. http://dx.doi.org/10.1016/j.ecolecon.2009.11.007

Gossen, H.H. (1854). Entwickelung der Gesetze des menschlichen Verkehrs, und der daraus fließenden Regeln für menschliches Handeln [Development of the laws of human intercourse, and the rules following therefrom for human action]. Friedrich Vieweg und Sohn, Braunschweig.

Gram, J.P. (1876). Om Modenhedsalderens Bestemmelse den største Entrepreneurførtjeneste [On Maximum Entrepreneurial Profit as a Criterion for Determining Age of Maturity]. Tidsskrift for Skovbrug 1: 85–105, 246–261. (In Danish)
Gras, N.S.B. (1925). A History of Agriculture in Europe and America. Pitman & Sons, London.
Griffin, R.C. (2012). The Origins and Ideals of Water Resource Economics in the United States. Annual Review of Resource Economics 4: 353–377. http://dx.doi.org/10.1146/annurev-resource-110811-114517
Grøn, A.H. (1931). Den almindelige skovøkonomis teori [A General Theory of Forest Economics]. Levin & Munksgaard, København. (In Danish)
Grøn, A.H. (1943). Skovbrugets driftsøkonomi I: Skovbrugets teoretiske driftsøkonomi [Economics of Forestry]. København. (In Danish)
Grøn, A.H. (1960). The work and influence of Christian Ditlev Fredrik Viscount Reventlow. In: Reventlow, C.D.F. A treatise on forestry. Society of Forest History, Hørsholm. p. 13–35.
Habakkuk, H.J. (1958). The market for monastic property, 1539–1603. The Economic History Review 10: 362–380.
Hagemann, H. (1996). German economic journals and economic debates in the nineteenth century. History of Economic Ideas 4: 77–102.
Hagemann, H. (2001). The Verein für Sozialpolitik from its foundation (1872) until World War I. In: Augello, M.M., Guidi, M.E.L. (eds.) The Spread of Political Economy and the Professionalisation of Economists. Routledge Studies in the History of Economics. Routledge, London. p. 152–175.
Hagemann, H., Rösch, M. (2012). Economic textbooks in the German language area. In: Augello, M.M., Guidi, M.E.L. (eds.) The economic reader: Textbooks, manuals and the dissemination of the economic sciences during the nineteenth and early twentieth centuries. Routledge Studies in the History of Economics. Routledge, London. p. 96–123.
Hald, A. (1990). A History of Probability and Statistics and Their Applications before 1750. Wiley, Hoboken, NJ. http://dx.doi.org/10.1002/0471725161
Hall, P. (ed.) (1966). Von Thünen’s Isolated State, Parts I and II. Pergamon Press, Oxford.
Hammersley, G. (1957). The Crown woods and their exploitation in the sixteenth and seventeenth centuries. Bulletin of the Institute Historical Research 30: 136–161. http://dx.doi.org/10.1111/j.1468-2281.1957.tb01369.x
Haney, L.H. (1913). History of economic thought; a critical account of the origin and development of the economic theoris of the leading thinkers in the leading nations. Macmillan, New York.
Hansen, J.F. (1877). Et Afsnit af Læren om Skovbrugets Økonomi [A Paragraph on Forest Economics]. Gad, Copenhagen.
Harrison, P. (2001). Rational equity valuation at the time of the South Sea Bubble. History of Political Economy 33: 269–281. http://dx.doi.org/10.1215/00182702-33-2-269
Harrison, P. (2004). What can we learn for today from 300-year-old writings about stock markets? History of Political Economy 36: 667–688. http://dx.doi.org/10.1215/00182702-36-4-667
Hart, M. ’t, Jonker, J., Zanden, J.L. van. (eds.) (1997). A financial history of The Netherlands. Cambridge University Press, Cambridge. http://dx.doi.org/10.1017/CBO9780511559754

Hartlib, S. (1652). Design for plenty; by a universal planting of trees. London.
Hasel, K. (1985). Forstgeschichte. Ein Grundriß für Studium und Praxis. Paul Parey, Hamburg und Berlin.
Hasel, K., Schwartz, E. (2002). Forstgeschichte. Ein Grundriss für Studium und Praxis. 2. aktualisierte Auflage. Kessel, Remagen.
Hayek, F.A. von. (1936). The mythology of capital. Quarterly Journal of Economics 50: 199–128.
http://dx.doi.org/10.2307/1885022
Hayes, R. (1726). The Money'd Man's Guide: or, the Purchaser's Pocket-Companion. London.
Hayes, R. (1727). A New Method for Valuing Annuities upon Lives. London.
Heckscher, E.F. (1912). Skogbrukets räntabilitet [Profitability of Forestry]. Ekonomisk Tidskrift 14: 139–156, 253–276. (In Swedish)
http://dx.doi.org/10.2307/3437831
Heichelheim, F.M. (1958–1970). An Ancient Economic History. 3 vols. Sijthoff, Leiden. Original German edition in 1938: Wirtschaftsgeschichte des Altertums. Sijthoff, Leiden.
Heikkilä, T. (1922). Verotuksemme vaikutuksesta metsätaloutemme kannattavaisuuteen [Taxation and profitability of forestry]. Metsätaloudellinen Aikakauskirja. Finnish Forestry Association, Helsinki. p. 198–204. (In Finnish)
Heikkilä, T. (1929). Der forstliche Zinsfuss. Acta Forestalia Fennica 34.7. The Finnish Society of Forest Science, Helsinki.
Heikkilä, T. (1930). Kiertoaika [Forest rotation]. In: Ilvessalo, L., Ilvessalo, Y. (eds.) Maa ja metsä IV. Metsätalous III. WSOY, Porvoo. p. 764–778. (In Finnish)
Heikkilä, T. (1952). Metsän arvon laskemisesta [On forest valuation]. Metsätieteellisen tutkimuslaitoksen julkaisuja 40.35. Finnish Forest Research Institute, Helsinki. (In Finnish)
Helles, F., Linddal, M. (1997). Early Danish contributions to forest economics. Journal of Forest Economics 3: 87–103.
Helmedag, F. (2008). The optimal rotation period of renewable resources: theoretical evidence from the timber sector. In: Fabozzi, F.J., Füss, R., Kaiser, D.G. (eds.) The Handbook of Commodity Investing. Wiley, Hoboken, NJ. p. 145–166.
http://dx.doi.org/10.1002/9781118267004.ch6
Heresbach, C. (1577). Foure Bookes of Husbandrie. Richard Watkins, London. Original Latin edition in 1570: Rei Rusticae Libri Quatuor. Birckmann, Cologne.
Hermann, F.B.W. (1832). Staatswirthschaftliche Untersuchungen. München.
Heske, F. (1938). German Forestry. Yale University Press, New Haven, CT.
Hess, R. (1885). Lebensbilder hervorragender Forstmänner und um das Forstwesen verdienter Mathematiker, Naturforscher und Nationalökonomen. Paul Parey, Berlin.
Heyer, G. (1865). Anleitung zur Waldwerthrechnung. Teubner, Leipzig.
Heyer, G. (1871). Handbuch der forstlischen Statik. Erste Abteilung. Die Methoden der forstlichen Rentabilitätsrechnung. Teubner, Leipzig.
Hicks, J.R. [1939] 1946. Value and Capital: An Inquiry into Some Fundamental Principles of Economic Theory. 2nd edition. Claredon Press, Oxford.
Hiley, W.E. (1930). The Economics of Forestry. Oxford University Press, Oxford.
Hirshleifer, J. (1974). Sustained yield versus capital theory. In: Dowdle, B. (ed.) The Economics of Sustained Yield Forestry: A Symposium. College of Forestry, University of Washington, Seattle.
Holmertz, C.G. (1876). Studier i skogstaxation [Studies on forest taxation]. Del 1. Norstedts, Stockholm. (In Swedish)

Homer, S., Sylla, R. (1996). A History of Interest Rates. Rutgers University Press, New Brunswick, NJ.

Hosseini, H.S. (2003). Contributions of Medieval Muslim Scholars to the History of Economics and their Impact: A Refutation of the Schumpeterian Great Gap. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 29–45. http://dx.doi.org/10.1002/9780470999059.ch3

Hossfeld, J.W. (1805a). Vollständiges System zur Taxation der Hölzer und Regulirung der Forste. Diana 3: 91–226.

Hossfeld, J.W. (1805b). Einige Bemerkungen zur Nördlingerischen Abhandlung über die Werthsbestimmung eines Waldes. Diana 3: 420–448.

Hotelling, H. (1931). The economics of exhaustible natural resources. Journal of Political Economy 39: 137–175. http://dx.doi.org/10.1086/254195

Houghton, J. [1683] 1727–1728. Letter no. 3. In: A Collection of Letters for Improvement of Husbandry and Trade. Reprint in 1727–1728, Woodman, London. p. 258–282.

Houghton, J. [1701] 1727–1728. Letter nos. 484 and 485. In: A Collection for Improvement of Husbandry and Trade. Reprint in 1727–1728, Woodman, London. p. 176–182.

Hubacek, K., Bergh, J.C.J.M. van den. (2006). Changing concepts of 'land' in economic theory: From single to multi-disciplinary approaches. Ecological Economics 56: 5–27. http://dx.doi.org/10.1016/j.ecolecon.2005.03.033

Hudson, M. (2000a). How interest rates were set, 2500 BC-1000 AD. Máš, tokos and fœnus as metaphors for interest accruals. Journal of the Economic and Social History of the Orient 43: 132–161. http://dx.doi.org/10.1163/156852000511259

Hudson, M. (2000b). The mathematical economics of compound interest: a 4,000-year overview. Journal of Economic Studies 27: 344–363. http://dx.doi.org/10.1108/01443580010341853

Hyytiäinen, K. (2003). Integrating economics and ecology in stand-level timber production. Doctoral dissertation. Finnish Forest Research Institute, Research Papers 908.

James, N.D.G. (1981). A History of English Forestry. Basil Blackwell, Oxford.

James, N.D.G. (1996). A History of Forestry and Monographic Forestry Literature in Germany, France, and the United Kingdom. In: McDonald, P., Lassoie, J. (eds.) The Literature of Forestry and Agriculture. Cornell University Press, Ithaca. p. 15–44.

Jevons, W.S. (1865). The Coal Question; An inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines. Macmillan, London.

Jevons, W.S. [1871] 1888. The Theory of Political Economy. 3rd edition. Macmillan, London.

Johansson, P.-O., Löfgren, K.-G. (1985). The Economics of Forestry and Natural Resources. Basil Blackwell, Oxford.

Jones, C.C. (1958). Henry C. Taylor: Father of Agricultural Economics (1873–). Agricultural History 32: 196–197.

Jones, E.L. (1965). Agriculture and economic growth in England, 1660–1750: Agricultural Change. The Journal of Economic History 25: 1–18.

Jones, E.L. (ed.) (1967). Agriculture and economic growth in England, 1650–1815. Methuen, New York.

Jones, P. (1997). The Italian City-State: From Commune to Signoria. Claredon Press, Oxford.

Jordan, J., Ritter von. (1800). Grundsätze über die Abschätzung der Landgüter zur Prüfung der Oekonomen, Forstverständigen, und Rechtsgelehrten. Widtmann, Prag.

Judeich, F. (1871). Die Forsteinrichtung. Paul Parey, Berlin.
Kant, S. (2013). Post-Faustmann Forest Resource Economics. In: Kant, S. (ed.) Post-Faustmann Forest Resource Economics. Springer, Dordrecht. http://dx.doi.org/10.1007/978-94-007-5778-3_1
Katz, V.J., Parshall, K.H. (2014). Taming the Unknown. A History of Algebra from Antiquity to the Early Twentieth Century. Princeton University Press, Princeton, NJ.
Kerridge, E. (1953). The movement of rent, 1540–1640. The Economic History Review 6: 16–34. http://dx.doi.org/10.1111/j.1468-0289.1953.tb01483.x
Kerridge, E. (1968). Arthur Young and William Marshall. History Studies 1: 43–53.
Khan, M.A., Piazza, A. (2012). On the Mitra-Wan forestry model: A unified analysis. Journal of Economic Theory 147: 230–260. http://dx.doi.org/10.1016/j.jet.2011.11.010
Kindleberger, C.P. (1985). A Financial History of Western Europe. Allen & Unwin, London.
Klaes, M. (2003). Historiography. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 491–506. http://dx.doi.org/10.1002/9780470999059.ch33
Kling, C.L., Segerson, K., Shogren, J. (2010). Environmental Economics: How Agricultural Economists Helped to Advance the Field. American Journal of Agricultural Economics 92: 487–505. http://dx.doi.org/10.1093/ajae/aaq012
Knight, F.H. (1933). Capitalist Production, Time and the Rate of Return. In: Economic Essays in Honor of Gustav Cassel. Allen & Unwin, London. p. 327–342.
Knight, F.H. (1934). Capital, Time and the Interest Rate. Economica, New Series 1: 257–286.
Knight, F.H. (1935a). Professor Hayek and the Theory of Investment. The Economic Journal 45: 77–94. http://dx.doi.org/10.2307/2224581
Knight, F.H. (1935b). Professor Knight and the ‘Period of Production’: Comment [and] a Final Word. Journal of Political Economy 43: 625–627, 808. http://dx.doi.org/10.1086/254834
Knight F.H. (1936). The Quantity of Capital and the Rate of Interest. Journal of Political Economy 44: 433–463. http://dx.doi.org/10.1086/254957
Knight F.H. (1938). On the theory of capital: In reply to Mr. Kaldor. Econometrica 6: 63–82. http://dx.doi.org/10.2307/1910085
Kopf, E.W. (1926). The early history of the annuity. Preceedings of the Casualty Actuarial Society 13: 225–266.
Kraft, G. (1882). Zur Praxis der Waldwerthrechnung und forstlichen Statik. Klindworth, Hannover.
Krause, G.F. (1812). Anleitung zur Abschätzung und Berechnung des Geldwerths der Forstgrundstücke theils zum Behuf Veräußererung, theils zur Begründung der Anleihen. Leipzig.
Krug, L. (1805). Betrachtungen über den National-Reichthum des preussischen Staats, und über den Wohlstand seiner Bewohner. Erster Theil. Berlin.
Kröncke, C. (1813). Betrachtungen über den Kapithalwert eines Waldes, dessen Naturalertrag ausgemittelt ist, vorzüglich in Hinsicht der Veranschlagung desselben zur Versteuerung. Allgemeiner Kameral-Korrespondent 55: 241–243.

Kula, E. (2001). History of Environmental Economic Thought. Routledge Studies in the History of Economics. Routledge, London.
König, G. (1813). Anleitung zur Holztaxation, ein Handbuch für jeden Forstmann und Holzhändler. 2. Theil. Holztaxation. Becker, Gotha.
König, G. (1835). Die Forstmathematik. Becker, Gotha.
König, G. (1842). Die Forstmathematik. Zweite stark vermehrte Ausgabe. Becker, Gotha. (3. edition in 1846).
Langholm, O. (1984). The Aristotelian Analysis of Usury. Universitetsforlaget, Bergen.
Langholm, O. (1998). The Legacy of Scholasticism in Economic Thought. Cambridge University Press, Cambridge. http://dx.doi.org/10.1017/CBO9780511528491
Letwin, W. [1963] 1975. The Origins of Scientific Economics. English Economic Thought 1660–1776. Methuen, London. Reprint in 1975, Greenwood Press, Westport, CT.
Lewin, C.G. (1970). An early book on compound interest – Richard Witt's Arithmeticall Questions. Journal of the Institute of Actuaries 96: 121–132.
Lewin, C.G. (1981). Compound interest in the seventeenth century. Journal of the Institute of Actuaries 108: 423–442. http://dx.doi.org/10.1017/S0020268100040865
Lichtenberg, E., Shortle, J, Wilen, J., Zilberman, D. (2010). Natural Resource Economics and Conservation: Contributions of Agricultural Economics and Agricultural Economists. American Journal of Agricultural Economics 92: 469–486. http://dx.doi.org/10.1093/ajae/aaq006
Lindenfeld, D.F. (1997). The practical imagination: the German sciences of state in the nineteenth century. The University of Chicago Press, Chicago. http://dx.doi.org/10.7208/chicago/9780226482446.001.0001
Linnard, W. (1974). Arthur Standish: an appreciation of Evelyn's forgotten predecessor. Quarterly Journal of Forestry 68: 34–40.
Lloyd, W.F. (1934). A lecture on the notion of value. Roake and Varby, London.
Locke, J. [1668] 1975. Some of the consequences that are like to follow upon lessening of interest to 4 percent. In: Letwin, W. (ed.) The Origins of Scientific Economics. English Economic Thought 1660–1776. Greenwood Press, Westport. p. 273–300.
Locke, J. [1691] 1823. Some considerations of the consequences of the lowering of interest, and the raising the value of money. The Works of John Locke, a New Edition, in Ten Volumes. Volume V. Thomas Tegg, London.
Lowood, H.E. (1990). The calculating forester: quantification, cameral science, and the emergence of scientific forestry management in Germany. In: Frängsmyr, T., Heilbron, J.L., Rider, R.E. (eds.) The Quantifying Spirit in the 18th Century. University of California Press: Berkeley. pp. 315–342.
Lowood, H.E. (1991). Patriotism, Profit, and the Promotion of Science in the German Enlightenment. The Economic and Scientific Societies 1760–1815. Garland Publishing, New York.
Lowry, S.T. (1965). The classical Greek theory of natural resource economics. Land Economics 41: 203–208. http://dx.doi.org/10.2307/3144852
Löfgren, K.-G. (1983). The Faustmann-Ohlin theorem: a historical note. History of Political Economy 15: 261–264. http://dx.doi.org/10.1215/00182702-15-2-261
Löfgren, K.-G. (1990). The use and non-use of economics and mathematics in forest economics. The Swedish experience 1876–1976. Scandinavian Journal of Forest Research 5: 551–561.

http://dx.doi.org/10.1080/02827589009382638
Löfgren, K.-G. (1993). Economics and mathematics in forest economics: Some Swedish contributions. In: Jonung, L. (ed.) Swedish economic thought: Explorations and advancements. Routledge, London. p. 220–235.
Löfgren, K.-G. (1995). Knut Wicksell on the optimal rotation problem in forestry. Journal of Forest Economics 1: 153–163.
Löfgren, K.-G. (2002). Ohlin versus Heckscher and Wicksell on forestry. One win (points) and one draw. In: Findlay, R., Jonung, L., Lundahl, M. (eds.) Bertil Ohlin: a centennial celebration, 1899–1999. MIT Press, Cambridge, MA. p. 117–123.
Löfgren, K.-G. (2012). Forest Economics before and after 1979 seen from my window. Journal of Forest Economics 18: 91–93.
http://dx.doi.org/10.1016/j.jfe.2012.02.003
Löfgren, K.-G., Mattsson, L. (1995). Thorsten Streyffert (1892–1983) — economist and forester. Journal of Forest Economics 1: 395–407.
Mabbut, G. (1726). Tables for Renewing and Purchasing of the Leases of Cathedral-Churches and Colleges. J. Hayes, Cambridge. First edition in 1686, further editions in 1720, 1722, 1726, 1729, 1731, 1735, 1742, 1758 and 1808.
Magnusson, L.G. (2003). Mercantilism. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 46–60.
Manningham, T. (1712). The value of church and college leases consider'd, and the advantage of lessees made very apparent. J. Wyat, London.
Mantel, K. (1964). History of the international science of forestry with special consideration of Central Europe. In: Romberger, J.A., Mikola, P. (eds.) International Review of Forestry Research, Volume 1. Academic Press, New York, p. 1–37.
Mantel, K. (1980). Forstgeschichte des 16. Jahrhunderts unter dem Einfluss der Forstordnungen und Noe Meurers. Paul Parey, Berlin.
Manz, P. (1986). Forestry economics in the steady state: the contribution of J. H. von Thünen. History of Political Economy 18: 281–290.
Marcuzzo, M.C. (2008). Is history of economic thought a "serious" subject? Erasmus Journal for Philosophy and Economics 1: 107–123.
Markham, G. [1613] 1982. The English Husbandman. Reprint in 1982, Garland, New York.
Marshall, A. [1890] 1907. Principles of Economics. 5th edition. Macmillan, London.
Marshall, W. (1787). The Rural Economy of Norfolk: Comprising the Management of Landed Estates, and the Present Practice of Husbandry in that County. T. Cadell, London.
Marshall, W. (1808). A Review of the Reports to the Board of Agriculture: From the Northern Department of England, etc. Longman, Hurst, Rees, Orme; London.
Mascall, L. (1569). Of the Arte and Maner Howe to Plant and Graffe All Sortes of Trees. London.
Medema, S.G. (2003). The Economic Role of Government in the History of Economic Thought. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.). A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 428–444.
Medema, S.G., Samuels, W.J. (eds.) (2001). Historians of Economics and Economic Thought: The Construction of Disciplinary Memory. Routledge, New York.
Menger, C. (1871). Grundsätze der Volkswirtschaftslehre. Braumüller, Wien.
Mezey, E.W., Conrad, J.M. (2010). Real options in resource economics. Annual Review of Resource Economics 2: 33–52.
Mieroop, M. van de. (2005). The Invention of Interest. Sumerian Loans. In: Goetzmann, W.N., Rouwenhorst, K.G. (eds.) The Origins of Value: The Financial Innovations that Created Modern Capital Markets. Oxford University Press, Oxford. p. 17–30.

Mitra, T., Wan H.Y. Jr. (1985). Some theoretical results on the economics of forestry. Review of Economic Studies 52: 263–282.
Mitra, T., Wan H.Y. Jr. (1986). On the Faustmann solution to the forest management problem. Economic Theory 40: 229–249.
Montanus, C. (1807). Über die Abschätzung kleiner Stücke Hochwaldungen, die zu verkaufen sind. Journal für das Forst-, Jagd- und Fischereiwesen Nro 35: 545–553.
Montanus, C. (1808). Zu den Bemerkungen, welche in Nr. 44 dieses Journals 1807 zu dem Aufsatz über die Abschätzung des Werthes kleiner Waldstücke in Nr. 35, gemacht wurden. Journal für das Forst-, Jagd- und Fischereiwesen Nro 8: 124–127.
Moog, M. (2012). Der Etrangswertkalkül in der Waldbewertungsliteratur. In: Lück, W. (ed.) Jahrbuch für Wirschaftsprüfung, Interne Revision und Unternehmensberatung. p. 161–173.
Moog, M., Borchert, H. (2001). Increasing rotation periods during a time of decreasing profitability of forestry – a paradox? Forest Policy and Economics 2: 101–116.
Moog, M., Bösch, M. (2013). Interest rates in the German forest valuation literature of the early nineteenth century. Forest Policy and Economics 30: 1–5.
Moser, W.G. von. (1757). Grundsätze der Forst-Oeconomie. Brönner, Frankfurt und Leipzig.
Munro, J.H. (2003). The medieval origins of the ‘Financial Revolution’: usury, rentes, and negotiablity. The International History Review 25: 505–562.
Munro, J.H. (2008). The usury doctrine and urban public finances in late-medieval Flanders (1220–1550): rentes (annuities), excise taxes, and income transfers from the poor to the rich. In: Cavaciocchi, S. (ed.) Fiscal Systems in the European Economy from the 13th to the 18th centuries. Firenze University Press, Florence. p. 973–1026.
Munro, J.H. (2011). Usury, Calvinism, and Credit in Protestant England: from the Sixteenth Century to the Industrial Revolution. Working Paper no. 41, Department of Economics, University of Toronto.
Murphy, A.L. (2009). The Origins of English Financial Markets. Investment and Speculation before the South Sea Bubble. Cambridge University Press, Cambridge.
Möhring, B. (2001). The German struggle between the ‘Bodenreinertragslehre’ (land rent theory) and ‘Waldreinertragslehre’ (theory of the highest revenue) belongs to the past — but what is left? Forest Policy and Economics 2: 195–201.
Navarro, G.A. (2003). Re-examining the theories supporting the so-called Faustmann formula. In: Helles, F., Strange, N., Wichmann, L. (eds.) Recent Accomplishments in Applied Forest Economics Research. Kluwer, Dordrecht. p. 19–38.
Neal, L. (1990). The Rise of Financial Capitalism. International Capital Markets in the Age of Reason. Cambridge University Press, Cambridge.
Nemore, J. de. [c. 1236] 1991. De elementis arithmetice artis [Elements of Arithmetics]. Published as a printed book in 1496. Modern edition in 1991: Busard, H.L.L. (ed.) Jordanus de Nemore, De elementis arithmetice artis: A Medieval Treatise on Number Theory. 2 parts. F. Steiner, Stuttgart.
Neugebauer, O.E. (1951). The Exact Sciences in Antiquity. Princeton University Press, Princeton, NJ.
Newman, D.H., Wagner, J.E. (2012). Putting Samuelson’s Economics of Forestry into context: The limits of forest economics in policy debates. Journal of Natural Resources Policy Research 4: 215–218.
Noonan, J.T. Jr. (1957). The Scholastic Analysis of Usury. Harvard University Press, Cambridge, MA.

Nõu, J. (1967). Studies in the Development of Agricultural Economics in Europe. Reprinted from: Lantbrukshögskolans Annaler, Vol. 33. Almqvist & Wiksells Boktryckeri AB, Uppsala.

Nördlinger, J.S. (1805). Versuch den Werth der Waldungen zu bestimmen. Diana 3: 363–419.

O'Brien, D.P. (2003). Classical Economics. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 112–129.

Oderwald, R.G., Duerr, W.A. (1990). König-Faustmannism: A critique. Forest Science 36: 169–174.

Ohlin, B. (1921). Till frågan om skogarnas omloppstid. Ekonomisk Tidskrift 22: 89–113. English translation in 1995: Concerning the question of the rotation period in forestry. Journal of Forest Economics 1: 89–114.

Oppel, F.W. von. [1760] 1791. Die Abtheilung der Gehölze in jährliche Gehaue: eine Rechnungsaufgabe. Revised edition in 1791. Wather, Dresden.

Overton, M. (1998). Agricultural revolution in England. The transformation of the agrarian economy 1500–1850. Cambridge University Press, Cambridge.

Pacioli, L. (1494). Summa de arithmetica, geometria. Proportioni et proportionalita. Paganino de' Paganini, Venice.

Paprica, C. di. (1789). Gedanken über verschiedene Gegenstände der Forst-Cameral-Wissenschaft. Nürnberg.

Parker, R.H. (1968). Discounted cash flow in historical perspective. Journal of Accounting Research 6: 58–71.

Pearce, D. (2002). An intellectual history of environmental economics. Annual Review of Energy and the Environment 27: 57–81.

Petrini, S. (1937). Skogsuppskattning och skogsekonomi [Forest taxation and forest economics]. Hökerberg, Stockholm. (In Swedish)

Petrini, S. (1946). Skogsekonomiens grunder [Principles of forest economics]. Hökerberg, Stockholm. (In Swedish)

Petty, W. [1662a] 1899. A Treatise of Taxes and Contributions. In: Hull, C.H. (ed.) The Economic Writings of Sir William Petty. Cambridge University Press, Cambridge.

Petty, W. [1662b] 1997. Interest. In: Marquis of Lansdowne (ed.) The Petty Papers: Some unpublished writings of Sir William Petty. Vol I. Routlidge, London. p. 245–248.

Petty, W. [1672–1673] 1997. Forestry. In: Marquis of Lansdowne (ed.) The Petty Papers: Some unpublished writings of Sir William Petty. Vol II. Routlidge, London. p. 125–131.

Pfeil, F.W.L. (1822). Grundsätze der Forstwirthschaft in Bezug auf die Nationalökonomie und die Staatsfinanzwissenschaft. Erster Band. Staatwirthschaftliche Forstkunde. Darnmann, Züllichau und Freistadt.

Pfeil, W.F.L. (1823). Von der Ermittelung des Verkaufspreises veräussernder Waldungen. Kritische Blätter für Forst- und Jagdwissenschaft. Band I, Heft 2. p. 300–363.

Pfeil, F.W.L. (1824). Grundsätze der Forstwirthschaft in Bezug auf die Nationalökonomie und die Staatsfinanzwissenschaft. Zweiter Band. Forstfinanzwissenschaft. Darnmann, Züllichau und Freistadt.

Piazza, A. (2009). The optimal harvesting problem with a land market: a characterization of the asymptotic convergence. Economic Theory 40: 113–138.

Pisano, L. (1202). Liber abaci. In: Sigler, L.E. (2003). Fibonacci's Liber Abaci: A Translation into Modern English of Leonardo Pisano's Book of Calculation. Springer, New York.

Plat, H. (1594). The Jewell House of Art and Nature. London.

Plot, R. [1686] 1963. A discourse concerning the most seasonable time of felling of timber. Philosophical Transactions 16: 455–461. Reprint in 1963, Johnson Reprint Corporation, New York.

Poitras, G. (2000). The Early History of Financial Economics, 1478–1776. From Commercial Arithmetics to Life Annuities and Joint Stocks. Edward Elgar, Cheltenham.

Pressler, M.R. (1859). Der Rationelle Waldwirth und sein Waldbau des Höchsten Ertrags. Zweites Buch. Die forstlichen Finanzrechnung. Türk, Dresden.

Pressler, M.R. (1860). Aus der Holzzuwachslehre. Allgemeine Forst- und Jagd-Zeitung 36: 173–191. English translation in 1995: For the comprehension of net revenue silviculture and the management objectives derived thereof. Journal of Forest Economics 1: 45–87.

Purser, W. (1634). Compound interest and annuities the grounds and proportions thereof, with tables to divers rates most usuall etc: containing the art of decimall arithmetick, also the value of annuities, etc. London.

Quinn, T.J. II. (2003). Ruminations on the development and future of population dynamics models in fisheries. Natural Resource Modeling 16: 341–392.

Rau, K.H. (1826–1837). Lehrbuch der politischen Oekonomie. Band 1. Grundsätze der Volkswirtschaftslehre. Heidelberg. [Band 2: Grundsätze der Volkswirtschaftspflege. 1828. Heidelberg. Band 3 (in two parts): Grundsätze der Finanzwissenschaft. 1832, 1837. Heidelberg.]

Reventlow, C.D.F. (1810). A treatise on forestry. Edited by Grøn, A.H. 1960. Society of Forest History, Hørsholm.

Ricardo, D. [1817] 1951. On the Principles of Political Economy and Taxation. London. In: Sraffa, P., Dobbs, H.M. (eds.) The Works and Correspondence of David Ricardo. Cambridge University Press, Cambridge.

Richards, J. [1730] 1971. The Gentleman's Steward and Tenants of Manors Instructed. Reprint in 1971, Gregg International, Farnborough.

Richards, J. (1739). Annuities on Lives and for Limited Terms of Years Considered. J. Osborn, London.

Ries, A. [1522] 1995. Rechenbuch /auff Linien und Ziphren / in allerlaey Handthierung / Geschäfften unnd Kauffmanschafft. Frankfurt. Reprint in 1995, Satyr-Verlag, Darmstadt.

Robinson, T.J.C. (1989). Economic Theories of Exhaustible Resources. Routlidge, London.

Roover, R. de. (1944). Early accounting problems of foreign exchange. The Accounting Review 19: 381–407.

Roth, F. (1926). Forest Valuation. Volume II. Michigan Manual of Forestry. 2nd revised edition. Georg Wahr, Ann Arbor, MI.

Rutherford, M. (2001). Institutional Economics: Then and Now. Journal of Economic Perspectives 15: 173–194.

Rämö, J., Tahvonen, O. (2014). Economics of harvesting uneven-aged forest stands in Fennoscandia. Scandinavian Journal of Forest Research 29: 777–792.

Samuels, W.J. (ed.) (1983). Research in the History of Economic Thought and Methodology, vol 1, The Craft of the Historian of Economic Thought. JAI Press, Greenwich, CT.

Samuels, W.J., Biddle, J.E., Davis, J.B. (2003). Preface. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. xv–xvii.
http://dx.doi.org/10.1111/b.9780631225737.2003.00001.x

Samuelson, P.A. (1976). Economics of forestry in an evolving society. Economic Inquiry 14: 466–492. Reprint in 1995, Journal of Forest Economics 1: 115–149.

Sandmo, A. (2011). Economics Evolving: A History of Economic Thought. Princeton University Press, Princeton, NJ.

Sandmo, A. (2015). The early history of environmental economics. Review of Environmental Economics and Policy 9: 43–63.
http://dx.doi.org/10.1093/reep/reu018

Schumpeter, J.A. (1954). History of economic analysis. Oxford University Press, Oxford.

Schwappach, A. (1888). Handbuch der Forst- und Jagdgeschichte Deutschlands. 2 Bands. Springer, Berlin.

Scorgie, M.E. (1996). Evolution of the application of present value to valuation of non-monetary resources. Accounting and Business Research 26: 237–248.
http://dx.doi.org/10.1080/00014788.1996.9729514

Scorgie, M., Kennedy, J. (1996). Who discovered the Faustmann condition? History of Political Economy 28: 77–80.
http://dx.doi.org/10.1215/00182702-28-1-77

Scott, A.D. (1955). The fishery: The objectives of sole ownership. Journal of Political Economy 63: 116–124.
http://dx.doi.org/10.1086/257653

Sharp, L. (1975). Timber, science and economic reform in the seventeenth century. Forestry 48: 51–86.
http://dx.doi.org/10.1093/forestry/48.1.51

Sigler, L.E. (2003). Fibonacci's Liber Abaci: A Translation into Modern English of Leonardo Pisano's Book of Calculation. Springer, New York.

Silverman, P. (1990). The cameralist roots of Menger's achievement. In: Caldwell, B.J. (ed.) Carl Menger and his legacy in economics. History of Political Economy, annual supplement to volume 22. Duke University Press, Durham and London. p. 69–92.

Skeat, W.W. (2013). A Concise Etymological Dictionary of the English Language – Primary Source Edition. Nabu Press.

Smith, A. [1759] 1976. The Theory of Moral Sentiments. Edited by Raphael, D.D., Macfie, A.L. Oxford University Press, Oxford.

Smith, A. [1776] 1981. An Inquiry into the Nature and Causes of the Wealth of Nations. Edited by Campbell, R.H., Skinner, A.S., Todd, W.B. Liberty Press, Indianapolis.

Smith, G.A. (1982). Natural resource economic theory of the first conservation movement (1895–1927). History of Political Economy 14: 483–495.
http://dx.doi.org/10.1215/00182702-14-4-483

Smith, G.W. (1967). A brief history of interest calculations. Journal of Industrial Engineering 18: 569–574.

Solow, R.M. (1974). The economics of resources or the resources of economics. American Economic Review 64: 1–14.

Standish, A. (1611). The Commons Complaint. Stansby, London.

Standish, A. (1613). New Directions of Experience to the Commons Complaint, for the Planting of Timber and Firewood. London.

Standish, A. (1615). New Directions of Experience to the Commons Complaint, for the Increasing of Timber and Firewood. London.

Stein, P. (1999). Roman Law in European History. Cambridge University Press, Cambridge.
http://dx.doi.org/10.1017/CBO9780511814723

Steuart, J. (1767). An Inquiry into the Principles of Political Economy. London.

Stevin, S. (1582). Tafelen van Interest. In: Struik, D.J. (ed.) (1958). The Principal Works of Simon Stevin, Vol. II, Mathematics. Swets & Zeitlinger, Amsterdam. p. 25–455.

Stigler, G.J. (1941). Production and distribution theories. Macmillan, New York.

Stigler, G.J. (1965). Textual Exegesis as a Scientific Problem. Economica, New Series, Vol. 32: 447–450.
http://dx.doi.org/10.2307/2552771

Stisser, F.U. (1735). Einleitung zur Land-Wirthschaft der Teutschen, nach dem Oeconomie-, Policen- und Cammer-Wesen eingerichten. Ritter, Jena.

Stisser, F.U. (1737). Forst- und Jagd-Historie der Teutschen. Ritter, Jena.

Stisser, F.U. (1746). Einleitung zur Land-Wirthschaft und Policey der Teutschen: zum Unterricht in Oeconomie-, Policey- und Cammerwesen eingerichtet. Jena und Leipzig.

Streissler, E.W. (1990a). The influence of German economics on the work of Menger and Marshall. In: Caldwell, B.J. (ed.) Carl Menger and his legacy in economics. History of Political Economy, annual supplement to volume 22. Duke University Press, Durham and London. p. 31–68.

Streissler, E.W. (1990b). Carl Menger on economic policy: the lectures to Crown Prince Rudolf. In: Caldwell, B.J. (ed.) Carl Menger and his legacy in economics. History of Political Economy, annual supplement to volume 22. Duke University Press, Durham and London. p. 107–132.

Streissler, E.W. (2001). Rau, Hermann and Roscher: contributions of German economics around the middle of the nineteenth century. European Journal of the History of Economic Thought 8: 311–331.
http://dx.doi.org/10.1080/09672560110062951

Streyffert, T. (1938). Den skogsekonomiska teorin [Forest economic theory]. Svenska Skogsvårdsföreningens Förlag, Stockholm. (In Swedish)

Struik, D.J. (ed.) (1958). The principal works of Simon Stevin, Vol. II, Mathematics. Swets & Zeitlinger, Amsterdam.

Swetz, F.J. (1987). Capitalism and Arithmetic: The New Math of the Fifteenth Century. Open Court, LaSalle, Ill.

Tahvonen, O. (2004). Optimal harvesting of forest age classes: a survey of some recent results. Mathematical Population Studies 11: 205–232.
http://dx.doi.org/10.1080/08898480490513616

Tahvonen, O. (2011). Optimal structure and development of uneven-aged Norway spruce forests. Canadian Journal of Forest Research 41: 2389–2402.
http://dx.doi.org/10.1139/x11-130

Tahvonen, O., Salo, S. (1999). Optimal forest rotation with in situ preferences. Journal of Environmental Economics and Management 37: 106–128.
http://dx.doi.org/10.1006/jeem.1998.1055

Tahvonen, O., Viitala, E.-J. (2006). Does Faustmann rotation apply to fully regulated forests? Forest Science 52: 23–30.

Tartaglia, N. (1556). General Trattato di numeri, et misure. Troiano, Venice.

Taylor, H.C. (1905). An Introduction to the Study of Agricultural Economics. Macmillan, London.
http://dx.doi.org/10.5962/bhl.title.23695

Taylor, H.C., Taylor, A.D. (1952). The Story of Agricultural Economics. The Iowa State College Press, Ames, IA.

Thaer, A.D. (1798–1804). Einleitung zur Kenntniss der Englischen Landwirthschaft und ihrer practischen und theoretischen Fortschritte [Introduction to English Agriculture]. 3 Bands. Hahn, Hannover.

Thaer, A.D. (1809–1812). Grundsätze der rationellen Landwirthschaft. Berlin. 4 Bands. (4th English edition in 1852, The Principles of Agriculture. New York.)

Thirsk, J. (ed.) (1967). The Agrarian History of England and Wales, IV, 1500–1640. Cambridge University Press, Cambridge.

Thirsk, J. (1983). Plough and pen: agricultural writers in the seventeenth century. In: Aston, T.H., Coss, P.R., Dyer, C., Thirsk, J. (eds.) Social Relations and Ideas. Cambridge University Press, Cambridge. p. 295–319.

Thirsk, J. (ed.) (1985). The Agrarian History of England and Wales, Vol. V, 1640–1750: Agrarian Change. Cambridge University Press, Cambridge.

Thomson, R.B. (1942). An examination of basic principles of comparative forest valuation. Duke University, School of Forestry, Bulletin 6. Durham, NC.

Thünen, J.H. von. [1826, 1850] 1966. Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie. An English edition with an introduction by Peter Hall in 1966: Von Thünen's Isolated State, Parts I and II. Pergamon Press, Oxford.

Thünen, J.H. von. [1863] 2009. Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie. Dritter Theil. In: Suntum, U. van (ed.) The Isolated State in Relation to Agriculture and Political Economy. Part III. Palgrave Macmillan, Chippenham. http://dx.doi.org/10.1057/9780230274112

Topp, N. (2008). The impact of open access to fishing grounds: the history of Jens Warming's model. History of Political Economy 40: 671–688. http://dx.doi.org/10.1215/00182702-2008-028

Tracy, J.D. (1985). Financial Revolution in the Habsburg Netherlands: 'Renten' and 'Renteniers' in the County of Holland, 1515–1565. University of California Press, Berkeley-London.

Trenchant, J. (1558). L'Arithmétique de Ian Trenchant departie an troys livres ensemble un petit discours des changes; avec l'art de calculer aux getons. Lyon. (2nd edition in 1566)

Treviso Arithmetic (Arte del Abbacho). [1478] 1987. English translation (Art of the Abbacus) in Swetz, F., Capitalism & Arithmetic: The New Math of the 15th Century. Open Court Publishing, La Salle, Ill. p. 37–176.

Tribe, K. (1988). Governing Economy. Cambridge University Press, Cambridge.

Tribe, K. (2003). Historical schools of economics: German and English. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 215–230. http://dx.doi.org/10.1002/9780470999059.ch14

Turgot, A.R.J. [1767] 1977. Observations sur le Mémoire de M. de Saint-Péravy. Limoges. In: Groenewegen, P.D. (ed.) The Economics of A.R.J. Turgot. Martinus Nijhoff, The Hague. p. 43–95.

Tusser, T. [1573] 1984. Five Hundred Points of Husbandry. Oxford University Press, Oxford.

Varian, H.R. (1996). Intermediate microeconomics. A modern approach. 4th edition. Norton, New York.

Vaughn, G.F. (2006). The Resource Economics of Grover Pease Osborne: Author of America's First Textbook on Resource Economics. American Journal of Economics and Sociology 65: 587–603. http://dx.doi.org/10.1111/j.1536-7150.2006.00466.x

Viitala, E.-J. (2006). An early contribution of Martin Faustmann to natural resource economics. Journal of Forest Economics 12: 131–144. http://dx.doi.org/10.1016/j.jfe.2006.04.001

Viitala, E.-J. (2013). The discovery of the Faustmann formula in natural resource economics. History of Political Economy 45: 523–548. http://dx.doi.org/10.1215/00182702-2334785

Viner, J. (1978). Religious thought and economic society. History of Political Economy 10: 1–192. http://dx.doi.org/10.1215/00182702-10-1-1

Walras, L. [1874–1877] 1926. Éléments d'économie politique pure, ou théorie de la richesse sociale. 4th English edition in 1926: Elements of Pure Economics, or the theory of social wealth. Routledge, London.
Warming, J. (1911). Om grundrente af fiskegrunde. Nationaløkonomisk tidsskrift 49: 499–505. English translation with an introduction in 1983: On Rent of Fishing Grounds. History of Political Economy 15: 391–396.
Warming, J. (1931). Aalegaardsretten. Nationaløkonomisk tidsskrift 69: 151–162. English translation in 2010: The Danish Right to Eel Weir. History of Political Economy 42: 483–494.
Waterman, A.M.C. (2003). Mathematical modeling as an Exegetical Tool: Rational Reconstruction. In: Samuels, W.J., Biddle, J.E., Davis, J.B. (eds.) A Companion to the History of Economic Thought. Blackwell, Malden, MA. p. 553–570. http://dx.doi.org/10.1002/9780470999059.ch37
Watson, R. (1794). Preliminary Observations. General View of the Agriculture of the County of Westmoreland, with Observations on the Means of Its Improvement. Edited by A. Pringle. Chapman, Edinburgh.
Watson, R. (1818). Anecdotes of the Life of Richard Watson, Bishop of Llandaff. Richard Watson & Abraham Small, Philadelphia.
Watt, W.W. (1972). The Influence of Islam on Medieval Europe. Edinburgh University Press, Edinburgh.
Webster, W. (1620). The True Valuation of Annuities, Leases, Fines, and Reversions. London. (Second enlarged edition in 1629)
van der Wee, H. (1963). The Growth of the Antwerp Market and the European Economy, Fourteenth-Sixteenth centuries. 3 vols. Martinus Nijhoff, The Hague. http://dx.doi.org/10.1007/978-94-015-3878-7
White, L.H. (ed.) (2007). The Collected Works of F.A. Hayek. Volume 12. The Pure Theory of Capital. The University of Chicago Press, Chicago.
Wicksell, K. [1893] 1954. Über Wert, Kapital und Rente nach dem neueren nationalökonomischen Theorien. English translation in 1954: Value, capital and rent. Allen & Unwin, London.
Wicksell, K. [1901] 1967. Föreläsningar i nationalekonomi. Första delen: Teoretisk nationalekonomi. Berlingska Boktryckeriet, Lund. Reprint of the English translation in 1967: Lectures on Political Economy. Vol 1. Kelley, New York.
Witt, R. (1613). Arithmetical Questions: Touching the Buying or Exchange of Annuities, Taking of Leases for Fines or Yearly Rent, Purchase of Fee-Simples, Dealing for Present or Future Possessions, and Other Bargaines and Accounts. London.
Worlidge, J. (1669). Systema Agriculturæ. T. Johnson, London.
Zanthier, H.D. von. (1764). Kurzer systematischer Grundriß der practischen Forstwissenschaft. Allgemeines oeconomisches Forst-Magazin 4: 3–248.
Zincke, G.H. (1755). Anfangsgründe der Cameralwissenschaften. Jacobi, Leipzig.
Zschokke, H. (1804). Die Alpenwälder: für Naturforscher und Forstmänner. Tübingen.
Yin, R. (1997). An alternative approach to forest investment assessment. Canadian Journal of Forest Research 27: 2072–2078. http://dx.doi.org/10.1139/x97-175
Yin, R. (2001). Combining forest-level analysis with options valuation approach—a new framework for assessing forestry investments. Forest Science 47: 475–483.
Yin, R., Newman, D.H. (1996). The effect of catastrophic risk on forest investment decisions. Journal of Environmental Economics and Management 31: 186–197. http://dx.doi.org/10.1006/jeem.1996.0040

Yin, R., Newman, D.H. (1997). Long-run timber supply and the economics of timber production. Forest Science 43: 113–120.

Yin, R., Newman, D.H. (1999). A timber producer's entry, exit, mothballing, and reactivation decisions under market risk. Journal of Forest Economics 5: 305–320.

Yin, R., Pienaar, L.V., Aronow, M.E. (1998). The productivity and profitability of fiber farming. Journal of Forestry 98: 13–18.

Yin, R., Sedjo, R.A. (2001). Is this the age of intensive management? A study of loblolly pine on Georgia's Piedmont. Journal of Forestry 99: 10–17.

Young, A. (1768). A Six Weeks Tour Through the Southern Counties of England and Wales. W. Nicoll, London.

Young, A. (1770). A Six Months Tour Through the North of England. W. Strahan, London.

Young, A. (1771). The Farmer's Tour Through the East of England. W. Strahan, London.

Young, A. (1783). Annals of Agriculture and Other Useful Arts, Vol 1. London.

## APPENDICES

**APPENDIX 1**. First three pages of Faustmann's (1849b) celebrated article (title, denotations and formula highlighted).

# Allgemeine Forst- und Jagd-Zeitung.

Monat December 1849.

### Berechnung des Werthes, welchen Waldboden, sowie noch nicht haubare Holzbestände für die Waldwirthschaft besitzen.

Herr Oberförster v. Gehren hat in dem October-Hefte dieser Zeitung (Seite 361) seine Ansichten „über Geldwerthbestimmung des holzleeren Waldbodens" entwickelt, und hierauf sein Rechnungsverfahren gegründet; gleichzeitig forderte derselbe zu mehrseitiger Besprechung dieses wichtigen Gegenstandes auf. Da wir nun mit den Ansichten und dem Rechnungsverfahren des Herrn v. Gehren theils nicht ganz einverstanden sind, theils auch einer anderen Auffassung des Sachverhaltes wissenschaftliches Interesse und praktischen Werth beilegen zu dürfen glaubten: so erlauben wir uns in Folgendem das obige Thema nach unseren Ansichten, mit Bezugnahme auf diejenigen des Herrn v. Gehren, zu behandeln. Wir bemerken aber von vornherein ausdrücklich, daß wir bei unserer Rechnung ausschließlich den Standpunkt des Waldwirthschafters einnehmen; also nur den Werth berechnen, welchen holzleerer Waldboden von forstlichem Gesichtspunkt aus besitzt. Um jedoch diese Aufgabe vollständiger zu lösen, mußten wir auch, von demselben Gesichtspunkt aus, unsere Rechnung auf noch nicht haubare Holzbestände ausdehnen, d. h. nicht denjenigen Werth derselben berechnen, welcher in dem Verkaufspreis ihres jeweiligen Holzgehaltes besteht, — sondern denjenigen, welcher durch ihre Nutzbarkeit im haubaren Alter bedingt ist, — welcher ihnen nämlich im Systeme der Waldwirthschaft oder durch ihre Stellung im Umtriebe (der Betrieb mag aussetzend oder nachhaltig sein) zukommt. Die praktische Bedeutung der letzteren Rechnung ist leicht zu ermessen. Wir erlangen durch sie die nöthigen Aufschlüsse über den Waldwerth bei freiwilligen und gezwungenen Verkäufen (Expropriationen), bei Waldzerstörungen durch Feuer, Insekten, Menschen rc., bei Beurtheilung der vortheilhaftesten Betriebsart und Umtriebszeit, — und dabei ist das Verfahren selbst einfach, und seine Richtigkeit läßt sich durch verschiedene Proben erweisen. — Wir stützen uns auf das Zahlenbeispiel des Herrn v. Gehren, — rechnen aber mit Zinseszinsen, weil wir dieß für das Richtigere halten.

Wir unterscheiden zum Zweck unserer Rechnung den aussetzenden und nachhaltigen Betrieb; bei jedem sodann, ob die Fläche holzleer oder bestanden ist, und hierbei endlich, ob sie als eine für sich bestehende Betriebsclasse, oder als Theil einer anderen angesehen wird. Unter „Betriebsclasse" aber verstehen wir eine Waldfläche, welche in einer und derselben Betriebsart und Umtriebszeit steht, und daher behufs der Ertragsberechnung als einheitliches Ganzes betrachtet wird. Unsere hierher bezügliche Unterscheidung ist nöthig, weil sich der Geldwerth einer Betriebsclasse nicht im direkten Verhältnisse mit ihrer Vergrößerung oder Verkleinerung zu ändern scheint. Ferner zwischen Flächen, welche gegenwärtig holzleer oder bestanden sind, mußten wir darum einen Unterschied machen, weil der Waldeigenthümer durch den Abtrieb und Verkauf eines noch nicht haubaren Bestandes pecuniären Schaden erleiden, und daher hierfür, außer dem Werthe des Bodens, von dem Käufer desselben noch eine Entschädigung mit Recht verlangen kann. Letzteres ist auch der Grund, aus welchem wir die Berechnung des Geldwerthes von noch nicht haubaren Beständen in unsere Aufgabe mit einschlossen. Die Berechtigung endlich zu einer Unterscheidung zwischen aussetzendem und nachhaltigem Betrieb, in Bezug auf den Waldwerth, liegt auf flacher Hand, und wurde auch von Herrn v. Gehren anerkannt.

#### I. Aussetzender Betrieb.

Wir haben diejenige Art desselben im Auge, bei welcher sich alle Fällungen und Culturen gleichmäßig und gleichzeitig über die ganze Fläche ausdehnen, also die ganze Fläche mit gleichalterigem Holzbestand successiv bedeckt ist. Wir brauchen daher auch hier nicht die Unterscheidung zu machen, ob die fragliche Fläche als eine für sich bestehende Betriebsclasse, oder als Theil einer anderen angesehen wird. Denn durch Vergrößerung oder Verkleinerung einer solchen Fläche ändert sich nicht die Betriebseinrichtung, und mit dieser die Bedingungen der Ertragsberechnung, — sondern nur die Größe der Einnahmen und Ausgaben im direkten Verhältnisse zur Flächenausdehnung.

A. Gegenwärtig holzleerer Waldboden. Die Berechnung des Herrn v. Gehren ist richtig. Aber wir wollen auch die Größe der jährlichen Bodenrente (reiner Geldertrag) berechnen, durch deren einfache Kapitalisirung wir den Bodenwerth finden. Wir drücken sie allgemein in einer Formel aus, und entfernen dadurch einen Unterschied zwischen Wald- und Feldboden, welcher bezüglich der zeitlichen Wiederkehr ihrer Erträge und Unkosten besteht und, nach Herrn v. Gehren, die Werthberechnung des ersteren schwieriger, als die des letzteren, macht.

### Waldbodenrenten-Formel.

Wir müssen unsere Aufgabe, zu ihrer mathematischen Auflösung, also ausdrücken: Welches ist der reine Geldertrag, den ein jetzt holzleerer Waldboden immerwährend in jährlich gleicher Größe liefert? Dabei dürfen keine anderen, als normale Walderträge, so weit deren Erzielung in der Gewalt des Wirthschafters liegt, unterstellt werden. — Zwei verschiedene Auffassungen sind möglich, welche aber zu gleichen Resultaten führen.

1) Man verwandelt alle in der ersten Umtriebszeit erfolgenden Einnahmen und Ausgaben in gleich große jährliche und erfährt durch Subtraktion der letzteren von den ersteren das Gesuchte. Die Ausdehnung der Berechnung nur auf eine Umtriebszeit reicht darum hin, weil man annehmen muß, daß alle übrigen Umtriebszeiten, bezüglich des Eintreffens der Einnahmen und Ausgaben, jener vollkommen gleichen.

Wir setzen den Geldwerth des Haubarkeitsertrags . . . . . . . . . . . . . . . = E,
der in einer Umtriebszeit erfolgenden Durchforstungserträge zusammengenommen . . . . = D,
und den Reduktionswerth der letzteren am Ende der Umtriebszeit . . . . . . . . . . = rD;
sodann die Größe der im Beginne des Umtriebs nöthigen Culturkosten . . . . . . . . . = C,
und der jährlichen Ausgabe für Verwaltung, Schutz 2c. . . . . . . . . . . . . . . = A;
ferner die Umtriebszeit. . . . . . . . . . = u,
das Procent beim Discontiren . . . . . . = p,
und endlich die jährliche Bodenrente . . . . = R.

Zur Vereinfachung der Rechnung können wir alle Einnahmen und Ausgaben, welche nicht jährlich erfolgen, an das Ende der Umtriebszeit reduciren, und deren Differenz sodann in eine jährlich gleiche Geldrente verwandeln, welche zum ersten Male am Ende des ersten, zum letzten Male am Ende des letzten Jahres der Umtriebszeit, und dabei so oftmal eingeht, als die Umtriebszeit Jahre zählt.

Am Ende der Umtriebszeit aber beträgt der Geldwerth des Haubarkeitsertrags E, der Durchforstungen rD und der Culturkosten C (1,op)$^u$, — letzterer Werth mit negativer Bedeutung. Die in oben bezeichnete Jahresrente zu verwandelnde Größe beträgt daher:

$$E + rD - C\,(1{,}op)^u.$$

Nennen wir diese Jahresrente x, und berechnen wir den Kapitalwerth, welchen dieselbe am Ende der Umtriebszeit besitzt: so ist dieser, oder

$$x\,(1{,}op)^{u-1} + x\,(1{,}op)^{u-2} + x\,(1{,}op)^{u-3} + \ldots + x\,(1{,}op) + x = E + rD - C\,(1{,}op)^u.$$

Die linke Seite der vorliegenden Gleichung ist nach der Summen-Formel der geometrischen Reihe, d. h.

$$S = \frac{a\,(q^u - 1)}{q - 1},\ \text{soviel als}$$

$$\frac{x\,[(1{,}op)^u - 1)]}{0{,}op} = E + rD - C\,(1{,}op)^u;$$

demnach

$$x = \frac{0{,}op}{(1{,}op)^u - 1}\,[E + rD - C\,(1{,}op)^u].$$

Von dem Werthe dieser Jahresrente (x) muß aber noch die jährlich gleich große Ausgabe (A) für Verwaltung 2c. abgezogen werden, um in dieser Differenz den Werth der jährlichen Bodenrente (R) zu erhalten.

Also ist die gesuchte Waldbodenrenten-Formel:

$$R = \frac{0{,}op}{(1{,}op)^u - 1}\,[E + rD - C\,(1{,}op)^u] - A.$$

2) Zu derselben Formel gelangen wir, wenn wir alle bis ins Unendliche erfolgenden Einnahmen und Ausgaben auf die Gegenwart reduciren, und von der Differenz dieser Jetztwerthe das jährliche Zinseneinkommen suchen.

Die Einnahme (E + rD) erfolgt zum ersten Male nach u Jahren, kehrt immerwährend alle u Jahre wieder; daher ist ihr Jetztwerth, oder

$$K = \frac{E + rD}{(1{,}op)^u} + \frac{E + rD}{(1{,}op)^{2u}} + \frac{E + rD}{(1{,}op)^{3u}} + \ldots + \frac{E + rD}{(1{,}op)^{\infty}}$$
$$= \frac{E + rD}{(1{,}op)^u} : \left[1 - \frac{1}{(1{,}op)^u}\right] = \frac{E + rD}{(1{,}op)^u - 1}$$

(Nach der Summen-Formel für unendliche geometrische Reihen, d. i. $S = \frac{a}{1 - q}$)

Die Culturkosten-Ausgabe (C) erfolgt am Anfange des ersten Jahres, und kehrt alle u Jahre wieder. Ihr

Jetztwerth (K') berechnet sich daher wie derjenige (K) der Einnahme (E + rD), wenn wir C statt E + rD substituiren, und zu dem Werthe von K noch C hinzufügen; also

$$K' = C + \frac{C}{(1{,}op)^n - 1} = \frac{C\,(1{,}op)^n}{(1{,}op)^n - 1}.$$

Die Ausgabe (A) für Verwaltung rc. erfolgt am Ende jedes Jahres immerfort in gleicher Größe; daher ist ihr Jetztwerth, oder

$$K'' = \frac{A}{0{,}op}.$$

Die oben gemeinte Jetztwerth-Differenz, deren jährliches Zinseneinkommen der jährlichen Bodenrente entspricht, ist aber:

$$K - K' - K'' = \frac{E + rD}{(1{,}op)^n - 1} - \frac{C\,1{,}op^n}{(1{,}op)^n - 1} - \frac{A}{0{,}op}$$

$$= \frac{1}{(1{,}op)^n - 1}\,[E + rD - C\,(1{,}op)^n] - \frac{A}{0{,}op}$$

Das jährliche Zinseneinkommen, gleich der Waldbodenrente, ist demnach hier, wie oben, in der Formel ausgedrückt:

$$R = \frac{0{,}op}{1{,}op^n - 1}\,[E + rD - C\,(1{,}op)^n] - A.$$

Nun ist es leicht, den Werth des holzleeren Waldbodens oder B zu finden; es geschieht durch einfache Kapitalisirung der jährlichen Waldbodenrente. Also ist

$$B = \frac{R}{0{,}op} = \frac{E + rD - C\,(1{,}op)^n}{(1{,}op)^n - 1} - \frac{A}{0{,}op}.$$

Bezieht sich die vorstehende Rechnung auf die Flächeneinheit (Morgen), und nennt man die zu taxirende Morgenzahl F: so ist die Bodenrente der letzteren = R.F und ihr Bodenwerth = B.F.

Wenden wir nunmehr diese Formel auf das von Herrn v. Gehren gewählte Zahlenbeispiel an. — Im Laufe des Umtriebs erfolgen nachstehende Geldeinnahmen mit ihren an das Ende der Umtriebszeit reducirten Werthen, wobei p = 4 und n = 80 ist:

| | Jahr des Umtriebs. | — | Geldertrag in diesem Jahre. | — | Reductionswerth desselben am Ende der Umtriebszeit: Formel. | — | Zahlenfactoren. *) | — | Reductionswerth. |
|---|---|---|---|---|---|---|---|---|---|
| Durchforstungen: | 20 | — | 1.000 Pf. | — | $1000.(1{,}04)^{60}$ | = | 1000. 10,51962 | = | 10.520 Pf. |
| | 30 | — | 1.880 " | — | $1880.(1{,}04)^{50}$ | = | 1880. 7,10668 | = | 13.359 " |
| | 40 | — | 1.380 " | — | $1380.(1{,}04)^{40}$ | = | 1380. 4,80102 | = | 6.625 " |
| | 50 | — | 1.160 " | — | $1160.(1{,}04)^{30}$ | = | 1160. 3,23339 | = | 3.751 " |
| | 60 | — | 1.955 " | — | $1955.(1{,}04)^{20}$ | = | 1955. 2,19112 | = | 4.284 " |
| | 70 | — | 2.433 " | — | $2433.(1{,}04)^{10}$ | = | 2433. 1,48024 | = | 3.601 " |
| | | | Summe 9.808 " | — | — | | — | | Summe 42.140 Pf. |
| Haubarkeits-Ertrag: **) | 80 | — | 42.379 " | — | — | | — | | 42.379 " |

Es ist demnach . . . D = 9808;

und rD = 42140

$$\left(r = \frac{42140}{D} = \frac{42140}{9808} = 4{,}2965\right)$$

ferner ist . . . . . E = 42379.

Die Culturkosten am Anfange des ersten Umtriebsjahres betragen 540 Pf.; also . . C = 540

und $C\,(1{,}op)^n = 540\,(1{,}04)^{80} = 540 . 23{,}04979 = 12447.$

Die jährlichen Kosten für Verwaltung rc. hat Herr v. Gehren nicht in Rechnung gezogen, indem er dieselben gleich der jährlichen, gleichfalls außer Rechnung gelassenen, Einnahme aus den Nebennutzungen setzte. Wir nehmen erstere zu 48 Pf. oder A = 48 an.

Substituiren wir diese Werthe, so erhalten wir:

$$R = \frac{0{,}04}{1{,}04^{80} - 1}\,(42379 + 42140 - 12447) - 48$$

$$= 0{,}04 \times 0{,}04535 \times 72072 - 48 = 130{,}72 - 48$$

$$= 82{,}72 \text{ Pf.}$$

Die jährliche Bodenrente beträgt demnach 83 Pf. oder 6 Sgr. 10,72 Pf. (25 Kreuzer), und der Bodenwerth $82{,}72 \times \frac{100}{4} = 2068$ Pf., oder 5 Thlr. 23 Sgr. 4 Pf. (10 fl. 3 kr.). — Herr v. Gehren hat einen circa dreifach höheren Bodenwerth gefunden, als wir; dieß rührt davon her, daß derselbe nach geometrisch-mittleren Zinsen, und wir nach Zinseszinsen rechneten. Auf Seite 364 gibt derselbe auch den nach Zinseszinsen berechneten Bodenwerth, und zwar zu 9 Thlr. 2 Sgr. 3 Pf. an, welcher darum von dem unsrigen verschieden ist, weil Herr v. Gehren die Verwaltungs- rc. Kosten (= 48 Pf.) außer Rechnung ließ; die fernere Differenz von noch 1 Pf. hat in den vernachlässigten Decimalstellen ihren Grund. — Ob aber dieser geringe Bodenwerth durch zu gering angenommene Erträge, Holzpreise rc., oder ein

*) Wir entnehmen die Reduktionsfactoren aus den Zinsberechnungs-Tafeln, welche Herrn v. Gehren's „Anleitung zur Waldwerthberechnung" rc. (Kassel 1835) angehängt sind.

**) Wir nehmen den ganzen Ertrag im 80jährigen Bestandsalter als Haubarkeitsertrag an.

**APPENDIX 2**. Faustmann's (1849a, 289–292) early contribution on determining optimal forest harvests.

Faustmann (p. 289) began by posing the following question: "after how many years does the present value of a forest stand reach the maximum?" (*…nach wie viel Jahren ist die gegenwärtige Holzmasse eines Bestandes mit ihrem Preise so hoch gestiegen, dass ihr gegenwärtiger Werth ein Maximum ist?*). He noted that one can determine this point of time indirectly by trial and error but that it is also possible to derive it directly by using calculus.

To capture the essence of Faustmann's specifications, let us apply modern notation. Initial timber volume is $x_0$, interest rate $i$, and the time period until the final harvest is $t$, where $t = 0,1,2,...$ For timber growth rate Faustmann used a constant $z$ because explicit growth functions were not available. Thus after $t$ years, timber volume was $x_t = x_0 + x_0 zt = x_0(1 + zt)$. Timber price was assumed to increase at the same rate as timber volume. Faustmann acknowledged that this was not very reasonable assumption but pointed out that more detailed price functions did not exist.

Denoting initial timber price by $p_0$ and timber price after $t$ years by $p_t$, Faustmann wrote $x_0/x_t = x_0/[x_0(1 + zt)] = p_0/p_t$ and obtained $p_t = p_0(1 + zt)$. Thus income from the final harvest after $t$ years was

$$p_t x_t = p_0(1 + zt)x_0(1 + zt) = p_0 x_0(1 + zt)^2. \tag{A1}$$

Faustmann wrote the corresponding present value maximization problem as

$$\max_t y = \frac{p_0 x_0(1 + zt)^2}{(1 + i)^t}. \tag{A2}$$

Setting $dy/dt = 0$, he obtained

$$t = \frac{2}{\ln(1 + i)} - \frac{1}{z}\,. \tag{A3}$$

Then Faustmann derived the second order condition and obtained $d^2y/dt = -2z^2/(1 + i)^t < 0$ when $z \neq 0$. Making use of the approximation $\ln(1 + i) = 2.302\lg(1 + i)$, he rewrote equation (3) as

$$t = \frac{1}{1.151\,\lg(1 + i)} - \frac{1}{z}. \tag{A4}$$

Faustmann concluded that the most profitable cutting time depends on timber growth rate and interest rate. Setting $z = 0.03$ and $i = 0.04$ implied that a forest should be left standing for additional 18 years. He also pointed out that a forest should be cut immediately when $z = 1.151\,\lg(1 + i) = 0.0196$, i.e. when the timber growth rate reduces to two percent. This holds because in his setting this volume increment rate translated to a value growth rate of four percent, thus equaling the interest rate.

Faustmann's reasoning and calculations conform to the single rotation solution. Obviously he was aware of this limitation because in the subsequent paragraph he explicitly noted (p. 292) that one should also account for the successive usage of bare land *(...dass hierbei auch eine allmähliche Verwerthung des Bodens angenommen werden muss…*). Another apt remark concerned the importance of being able to formulate explicit timber growth and value functions (p. 292). After these fitting comments Faustmann proceeded in the article to show how to determine the value of bare land.

**APPENDIX 3**. Landmarks in the early development of modern forest economic thought.

| | **England/ financial revolution** | | **German states/scientific forestry** | | | | | | | | | | **England/ agricultural revolution** | | **German states/ classical forest science** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Houghton (1683, 1701) | Richards (1730) | Zincke (1755) | Moser (1757) | Oppel (1760) | Zanthier (1764) | Burgs-dorf (1796) | Jordan (1800) | Bein & Eyber (1801) | Nörd-linger (1805) | Hossfeld (1805a,b) | Montanus (1807), Anonymous (1807) | Watson (1794) | Marshall (1808) | König (1813, 1835, 1842) | Pfeil (1823, 1824) | Faustmann (1849a,b) | Pressler (1859, 1860) |
| Recognized the opportunity cost of standing timber | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Recognized the opportunity cost of bare land (or the need for an infinite time horizon in forest valuation) | √ | √ | √ | √ | | | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | √ |
| Used the 'Faustmann formula' to calculate forest value under sustained yield management | | √ | √ | √ | | | √ | √ | (1) | √ | √ | √ | | | (2) | | √ | √ |
| Used the 'Faustmann formula' to calculate forest value under intermittent management | | √ | | | (3) | (3) | | | (1) | | √ | √ (4) | | | (2) | | √ | √ |
| Derived the 'Faustmann rule' of optimal forest rotation age and harvesting | (5) | | | | | | | | | | (6) | | | (5) | (7) | (8) | (8) | √ |

(1) Derived forest values but used some unwarranted assumptions and approximations and made calculation errors.

(2) Applied the 'Faustmann formula' in numerical calculations but assumed that regeneration costs occur only once, in the beginning of the first rotation.

(3) Compared profitability of different tree species and management regimes with future value calculations involving finite time horizons but did not derive forest values.

(4) Montanus (1807) used exogenous bare land values.

(5) Articulated the principle underlying the 'Faustmann rule' but did not present any analytical formulations or calculations.

(6) Applied calculus to derive the optimal rotation age that maximises timber production (maximimum sustained yield, MSY).

(7) Introduced the concept 'net value increment percent' (*bodenfreie Werthzunahme-Prozent*, *reine Werthzunahme-Prozent*) which resembles Pressler's celebrated 'indicator percent' (*Weiserprozent*). As Pressler, relied on exogenous bare land values.

(8) Recognized explicitly that the formula for maximum land value can be used to determine the most advantageous silvicultural system and length of rotation.

**APPENDIX 4**. German and English pioneers of forest economic thought and forest economics.

German pioneers (no portraits available for Johann Wilhelm Hossfeld and Martin Faustmann):

Georg Heinrich von Zincke (1692–1769)

Gottlob König (1779–1849)

Johann Heinrich von Thünen (1783–1850)

Max Robert Pressler (1815–1886)

English pioneers (no portraits available for John Houghton, John Richards and William Marshall):

Sir William Petty (1623–1687)

Richard Watson (1737–1816)