R1: Methodological background

1. DETERMINATION OF THE DISCOUNT FACTOR

The choice of the discount factor has a crucial effect on economic parameters. Various authors discussed the choice of the discount factor and its effect on the land expectation value as one important example of these parameters in the context of forest management decisions such as the rotation time determination or thinning time (Brodie et al., 1978; Chang, 1998a, 1983; Haight et al., 1992; Möhring, 2001b). This demonstrates that the choice of the discount factor also influenced silvicultural strategies and decision-making. However, seen from an opportunity cost perspective, where the discount factor is representing the return of a comparable investment a forest holding can make in generating wood (Möhring, 2001a), it can also be concluded that silvicultural trends also affected the discount rate itself. Finally, independent of the point of view the discount factor is discussed, it turns out to be an essential part of silvicultural strategies from the 19th century until today.

1.1 A historical review on the discount factor discussion

The discount factor representing the second half of the 19th century was determined with 3 % according to Endres (1895). This discount factor was determined throughout intensive discussions of German forest economists throughout the second half of the 19th century. The interest rate common for forestry called “forstliche Zinsfuß” (the “forestry interest rate”) was determined as one percentage point below an average interest rate of country specific secure capital investments

like, e.g. government bonds (Oesten and Roeder, 2008). The reduction by one percentage point was justified with the special character of forestry, mainly its assumed safety and its easy convertibility into cash (Oesten and Roeder, 2008).

The „forestry interest rate“ was used throughout the first half of the last century, however it was more and more criticized as too high for determining the value of bare forest land. Kroth (1975) considers the defined discount factor as subjective value representing excessive expectations towards the return of the production factors labor and capital. From his perspective, there is no evidence for a commonly valid discount factor because there is no objective process of determining it. Depending on the purpose of valuation he recommends to base the calculations on an interest rate representing the profitability of a comparable investment in forestry (Kroth, 1975). This approach was already announced by Leischner (1954). He calculates the internal rate of return of spruce stands based on Mantel (1954) ranging between 1.6 % and 3.1 %, depending on the yield class chosen. For the epoch of 1980 until today, Möhring (2001a) can be cited, who determines an interest rate of 1.5 % as marginal efficiency of capital bound in spruce and beech stands in the Solling area, Germany (Müller and Hanewinkel, 2018). This is also supported by the work of Knoke (2012) who calculates interest rates for Central European forests between 1 % and 2 %. Taking up the discussion of Kroth (1975) it should be noted that even these forms of determining a discount factor are not much more objective than using the „forestry interest rate“ as also within this approach various assumptions have to be made upfront.

1.2 Declining interest rate as the solution for uncertainty about discounting

The choice of the discount factor is determinant on the economic feasibility of forest management and is also used to capture the risk related to forest stands, such as the occurrence of disturbances. Still, the determination of an adequate interest rate for forest investments is controversial (see supplementary material 8.1 for a historical perspective). Once looking at the historical discussions about the discount factor, we get the impression that there always existed a significant uncertainty about determining the right discount factor for forest valuation. Also Weitzman (2001) recognized the general uncertainty about choosing the right discount rate for analyzing environmental investments which will be spread out over hundreds of years.

In this article, we followed the ideas of Newell and Pizer (2003) and Weitzman (2001) basing our analyses on declining discount rates. In the context of forest valuation various authors (Brazee, 2018; Davies and Kerr, 2015) use the declining discount rates recommended for environmental investments by the British government (Treasury, 2003). We are aware that the basis of this rate might be slightly lower for Germany than for Great Britain (Oxera Consulting LLP, 2002). However, we decided not to adopt the interest rates postulated by Treasury (2003) and refer to the declining discount rates recommended in discrete form (cf. Table S1) as we were also talking about discrete time steps in our silvicultural models (cf. 2.4).

Table S1: Declining discount rate applied in this article (Treasury, 2003).

Period of years	Discount rate
0-30	3.5 %
31-75	3.0 %

76-125	2.5 %
125-200	2.0 %
201-300	1.5 %
301+	1.0 %

2. DETERMINATION OF LEV_{carbon}

For a harvesting regime including final cuttings after a given rotation period the LEV_{carbon} could be defined as:

$$LEV_{carbon} = \frac{\sum_{t=1}^{T}\left(\left(C_t^{above} - C_{t-1}^{above} - C_t^{harvest} - C_t^{mortality}\right)3.67\ P_C\right)w^{(T-t)}}{w^T - 1} \quad (1)$$

For carbon sequestration under continuous cover forestry, the net carbon changes are varying not that much over time as a constant standing stock is remaining on the land for perpetuity (Seidl et al., 2007). Therefore, the standing stock's carbon volume only could be accounted once as perpetual carbon sink.

Finally, it has to be pointed out that the market for carbon in Europe only exists since 2005 (Calel, 2013). As a market for carbon did not exist in two of the three epochs in focus, it was a crucial question how to determine a price for carbon sequestration before 2005. For comparison reasons we decided to assume the same price for carbon sequestration for all scenarios.

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