An Economic Model to Assess the Long-Term Implications for Investments Aimed at Urban Sustainability

Antonio Nesticò and Gabriella Maselli

Abstract The long "life" of investments aimed at the sustainable development of the urban and built environment generates benefits, costs, and risks over a longer period than that of the generations that evaluate them. In this regard, reference should be made to environmental externalities, such as greenhouse gas emissions, which must be taken into account in the studies. This requires the use of logic that allows attributing the right weight to inter-generational effects in economic analyses. For this reason, the paper focuses on the choice of the Social Discount Rate (SDR) to be used in Cost-Benefit Analysis (CBA) of projects with long-term implications. In fact, social discounting is generally carried out using time-constant discount rates. Nevertheless, the resulting excessive contraction for Cash Flows (CFs) progressively more distant in time, leads to employing time-declining discount rates. Thus, the aim of this work is to propose an innovative model for the estimation of Declining Discount Rates (DDRs) based on probabilistic logic algorithms. The model, which is easy to implement in practice but always anchored to the theoretical principles of the reference literature, can become a determining tool for decision-making purposes since it leads to a good dimensioning of the long-term effects that sustainable urban development projects determine.

Keywords Urban sustainability · Economic evaluation of projects · Social discounting · Declining discount rate (DDR)

1 Introduction

Investments aimed at sustainable development of the urban environment and built environment generate multiple effects over a long time horizon. In this regard it is worth mentioning, among others: urban forestry interventions, which reach the regime phase after 15–25 years from planting; projects that aim to reduce greenhouse

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gas emissions, whose initial costs are very high while the benefits are carried out for centuries; infrastructure investments in the territory; but also the interventions on water resources, for which the beneficiary generations are often different from those that bear the costs [1–4]. In such cases, it is necessary to evaluate the totality of the costs and benefits generated by the initiatives, including those progressively more distant in time, rarely correctly taken into account in the studies. This is because the choice of the Social Discount Rate (SDR) influences significantly the outcome of a Cost-Benefit Analysis (CBA). A crucial economic parameter in economic analyses is the SDR that allows financially comparing of the Cash Flows (CFs) that occur in different periods. The discounting of financial items at time t generally takes place via an exponential "discount factor" function $F_s = e^{-SDR \cdot t}$. This leads, however, to an excessive contraction of the financial terms gradually more distant from the moment of the evaluation. In order to attribute a "right" weight to the long-term economic effects, which are consistent for investments with inter-generational repercussions, recent studies propose to resort to hyperbolic discounting, or through time-declining discount rates [1–6].

Thus, the aim of this research is to characterize an estimation model of the Declining Discount Rates (DDRs) based on probabilistic algorithms. The first attempt is to define a tool that is of simple use and that, while overcoming some limits of the main approaches of the reference literature, is still anchored to principles of unquestionable theoretical validity. The second attempt is to propose an economic evaluation model that considers both the problem of inter-generational equity and the multiple environmental and social externalities generated by the project. For more information on the topic, see [7, 8].

2 A Theoretical Approach for Estimating DDR. A Critical Review

In the last few decades, two approaches have mainly emerged for estimating the declining discount rate: the *Consumption-Based Approach* (a) and the *Expected Net Present Value Approach* (b).

The approach (a) is based on the methodology most used in Europe for the estimation of the Social Discount Rate (SDR), i.e., on the known Ramsey formula (1928)

$$SDR = \rho + \eta \cdot g \tag{1}$$

where $\rho$is the time preference rate or rate at which individuals discount future utility; η is the elasticity of marginal utility with regard to consumption; g is the exchange rate in per capita consumption, generally understood as expected growth rate of consumption. The hypothesis to consider for long periods that the shocks at the growth rate of consumption g are uncertain but positively correlated determines a

Table 1 Limits and relevant aspects related to the theoretical approach for estimating the DDR

	Limits	Relevant aspects
Consumption-based approach	– Use of the complex econometric model for the forecast of g	– Use of the Ramsey formula
Expected net present value approach	– Shortage of link to the theory of BCA – Forecast based on the government bonds – Use of the complex econometric model for the forecast of SDR	– Computational simplicity in the estimate of the certainty-equivalent discount factor d_t and discount rate $\tilde{r}_t$

structure of the function of the discount rate declining over time [9, 10]. Different and ever-increasing complexity is related to the econometric models that can be used to forecast the uncertain parameter g and, consequently, the SDR according to approach (a).

Instead, following the Expected Net Present Value Approach (b) proposed by Weitzman [11], the forecast of future discount rates is based on government bonds and the uncertainty concerns the value of the discount rate SDR. This uncertainty determines a time-declining path of the variable SDR, estimating the expected discount factor d_t associated with the distribution of the possible rates that occur at future moments t [11].

The conversion of d_t for each future year t into the "certainty-equivalent" discount rate $\tilde{r}_t$, understood as the exchange rate of the expected discount factor allows to obtain a time-declining rate function.

Table 1 summarizes the main critical issues as well as the relevant aspects relating to the two approaches.

3 Characterization of a Probabilistic Model to Estimate DDRs for the Economic Evaluation of Projects with Long-Term Effects

The model for the estimation of DDRs to be used in economic analyses of projects with inter-generational effects is based on the well-known Ramsey formula, which expresses an estimation approach of the SDR among the most used in practice. In order to avoid resorting to econometric models that often presuppose stringent preliminary hypotheses, the main novelty of the model concerns the rate of growth of consumption g on which the value of the discount rate SDR depends, which is modeled as a stochastic variable. In extreme synthesis, through the Monte Carlo analysis a series of probable values is determined to be associated with the rate g and, consequently, to the unknown SDR.

Figure 1 details the logical-operative steps on which the probabilistic model for estimating the DDR is based.

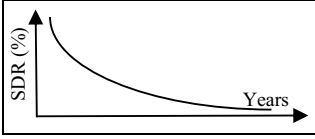
Analysis of the socio-economic conditions of the Country in which the project is located	Ramsey Formula: $SDR = \rho + \eta \cdot g$ (1) ρ = time preference rate η = elasticity of marginal utility with regard to consumption g = expected growth rate of consumption a. Estimate of the deterministic parameters ρ an η
Forecast of the uncertain parameter g	b. Analysis of the historical data trend c. Definition of the probability distribution of the historical trend d. Monte-Carlo analysis to forecast the possible future value of g and then *SDR* using (1)
Estimate of the Declining Discount Rate $\tilde{r}_t$	e. Estimate the certainty-equivalent discount factor d_t $d_t = \sum L_i (1 + r_i)^{-t}$ (2) L_i is the probability that the review has to occur at the generic instant t of the project analysis period f. Estimate the certainty-equivalent discount rate $\tilde{r}_t$ $(1+\tilde{r}_t) = \frac{d_t}{d_{(t+1)}}$ (3)
	Possibility to consider in economic studies the totality of the Costs and the Benefits, as well as long term, generated by investment aimed at sustainable development of urban and built environment

Fig. 1 Characterization of the probabilistic model to estimate DDRs

4 Conclusions

In CBAs, giving due weight to long-term externalities can be done through a careful estimate of the Social Discount Rate (SDR). As an economic parameter necessary to discount the CFs over time, the SDR strongly influences the result of a cost-benefit test. In fact, if the social discounting is carried out with a time-constant discount rate, the financial terms that are more distant over time risk being excessively contracted. The implementation of the model on Italian economic data showed that the use in CBA of time-declining discount rates (between 3.5 and 2%) leads to a Net Present Value (NPV) that is about twice as high as that obtained with a time-invariant rate equal to 3%. So, in order to avoid the long-term effects of the interventions aimed at sustainable development are underestimated, this research focuses on the importance of resorting to hyperbolic discount, and then to time-declining discount rates. To this end, an innovative model for the estimation of DDR based on a probabilistic logic is characterized. With the aim of overcoming the limits of recognized theoretical approaches in literature, the proposed methodology can become a useful support tool for decision-making. Based on readily available data but still based on rigorous theoretical principles, the attempt is to make more transparent and more coherent the process of allocating public resources to projects that are sustainable even for future generations.

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