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Revisiting Social Discount Rates for Public Investment†

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This paper aims to estimate the social discount rate (SDR) rather than dig into its theoretical foundation. As SDRs can be derived by investigating both the rate of return on investment and the social time preference rate, we estimate the marginal productivity of both private and public capital and the time preference rate based on the Euler equation. In order to provide a single representative SDR, the weighted averages of the marginal productivity and time preference rate, whose weights are determined by the flow of funds data reflecting the social demand of funds, are presented. Based on the empirical results, we argue that the marginal productivity of private capital stands in the middle of the 3% range while that of public capital varies from 4.5% to 8.6%, with the time preference rate showing a decreasing trend from 3.2% in the early 2000s to 1.2% by around 2030. The single representative SDR or the weighted SDR is estimated to be approximately 3.0~4.5% and expected to continue its downward trend for the foreseeable future.

Key Word: Social Discount Rate, Opportunity Cost of Capital,
Rate of Time Preference
JEL Code: H5, H8

I. Introduction

Social overhead capital (SOC) is not only an important production factor for economic growth but also a public good that provides public services which have the potential to increase social welfare. A lack of social overhead capital can lead to the deterioration of national competitiveness due to the increase in logistics costs, while an excessive supply of social overhead capital can lead to distortions in how resources are allocated, lower efficiency of public investments, and increased levels of national debt. Therefore, deciding how much to invest, how to allocate

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the determined investment resources to which businesses, and maximizing the efficiency of the investment are key issues. The discount rate in social overhead capital supply decisions, also referred to as the social discount rate (SDR), is related to the economic feasibility analysis of the public investment project. It is the most important parameter when calculating the benefit-cost ratio. Nevertheless, there is no practical agreement on the rationale and method of analysis with regard to setting the SDR and analysis period such that they can be applied to the economic feasibility analysis of public investment projects.

Owing to the nature of these types of investment projects, the costs are concentrated in the initial stage of the project, whereas the benefits are realized gradually throughout the analysis period after the project costs are paid beforehand. Therefore, if the SDR exceeds an appropriate level, a project can be mistaken as economically unjustifiable via a cost-benefit analysis despite the fact that it may be in fact economically feasible, thus resulting in social underinvestment. In contrast, if the SDR is lower than an appropriate level, the project is approved even if it is not economically feasible, which leads to a waste of resources due to the excessive social investment. In particular, this problem is more severe in public projects, which must consider congestion costs due to road construction and environmental gains from the construction of parks and similar projects compared to private projects, which only consider the opportunity cost of capital through cash inflows and outflows.

In most feasibility studies in Korea, the SDR of the Preliminary Feasibility Study by the Korea Development Institute (KDI) is used. KDI has gradually adjusted the SDR to reflect the characteristics of the project and to account for changes in economic conditions (Korea Development Institute, 2008). When the first survey was introduced in 1999, the real SDR of 7.5% was applied to all types of projects, except for a water resource development project,[1] and this was lowered to 6.5% in 2004.[2] Since 2008, a SDR of 5.5% has been applied to reflect changes in the capital market due to low interest rates and low growth.[3] However, as the population growth rate is declining due to low fertility and given that population aging is becoming more obvious, it is expected that the growth potential of the economy will be lowered as the accumulation of physical capital decelerates due to the low interest rates and saving rates. As shown in Figure 1, the SDR used by KDI has been consistently higher than the Korea Treasury Bond (KTB) interest rate since 2000, and it can be confirmed that the interest gap between the KTB and the SDR is widening. Considering this situation, it is necessary to examine whether the current SDR is appropriate.

As the nature of public projects reflects the investment and economic conditions of the time, it is desirable for the SDR also to change over time. However, in practice, using different SDRs every year will lead to significant confusion considering that the profitability of the same project will change from year to year.

[1]For water sector projects, a social discount rate of 6.0% has been applied, considering that these projects should be considered as lasting longer than other sector projects.

[2]For water sector projects, a social discount rate of 6.5% was applied for the first 30 years of operation, after which 5.0% was applied for the following 20 years.

[3]For water sector projects, a social discount rate of 5.5% was applied for the first 30 years of operation, after which 4.5% was applied for the following 20 years.

FIGURE 1. KDI SDR AND MARKET RATES

Note: Social Discount indicates KDI SDR.

Source: Bank of Korea ECOS.

However, if the economic conditions or the investment environment change over time, an adjustment of the SDR will be inevitable. This paper focuses on estimating the SDR by reflecting policies and practical demand levels rather than the theoretical aspects of the SDR. In addition to monetary benefits and costs, there are no clear criteria regarding how to set social opportunity costs in economic analyses of public projects to which non-monetary benefits and costs must be added4. The SDR varies depending on the economic conditions and the assumptions of the model; hence, care is necessary when interpreting these estimates and their real-life implications. Although different models may result in different SDRs, we argue that the comparison between different social investment projects should be made with the same model to measure the economic effectiveness and to rank the order of the social desirability of the candidate projects.

In this paper, we propose three methods to estimate the SDR: (1) the rate of return on investment, (2) the rate of time preference, and (3) the weighted average of rate of returns and time preference. In principle, if the source of public investment comes from a reduction in consumption, the time preference rate should then be used, whereas if it comes from a reduction in investment, it is reasonable to use the return on investment for the SDR. However, in actuality it is challenging to discern the funding sources of public investments. For this reason, it is inevitable to conjecture that the source of public investment comes partly from a decrease in consumption and partly from a decrease in investment. Under this assumption, one

[4]According to Baumol (1968), the opportunity cost of public investment introduces the question of whose sacrifice is necessary for the investment resources to be financed under the constraints of available resources. For public investments, where the funds used for the project come from a reduction in private consumption, consumers' time preferences should be used for the social discount rate, and the pre-tax return on the investment should be used as the social discount rate when the funds used are from private investment.

needs to devise the weighted average of the rate of return from private investment and rate of time preference, whose weights should be determined by the relative amounts of funds between consumption and investment.

This paper is organized as follows. Chapter II explains the key parameters in the evaluation of public investment projects and Chapter III introduces the empirical models used to estimate the SDR. Section IV presents the data and discusses the results from the empirical analysis. Finally, Section V summarizes the discussion and provides conclusions.

II. SDR: Overview

The discount rate is a factor used to convert the future benefits and costs to the value of a specific reference date to determine whether to conduct business or to prioritize an investment. There are various discount factors depending on the purpose of use and the subject of application. Although the primary goal of this paper is to estimate the working values of the SDR, there will be limitations when attempting to interpret the results of the empirical analyses without a clear understanding of the theoretical background of the SDR. The following is a brief description to provide a conceptual understanding of the SDR, as well as the difference between the private discount rate and the SDR.

A. *Measurement of the SDR*

The SDR discussed in this paper is the discount rate applied to public projects carried out by public institutions for the public interest, whereas the financial discount rate is mainly applied in corporate investments and is also commonly referred to as the return on investment. The SDR is distinguished from the financial return only for individual economic entities in that it reflects incidental and indirect benefits and external effects from a social point of view as well as direct benefits from the performance of specific projects (Lee *et al.*, 2001). Moreover, in the cost-benefit analysis, which evaluates the economic feasibility of public projects using the SDR, the benefit and cost of the cash equivalent should be taken into account despite the fact that direct cash flows do not occur. This differs from the corporate investment case, where only cash inflows and outflows are accounted for in project evaluations.[5]

Regarding the SDR, the appropriate level and trend of real interest rates have been investigated and documented in the literature. Wicksell (1934) argues that the real interest rate is determined by the demand for capital, which is closely related to the marginal productivity of capital.6 In contrast, Fisher (1930) stresses that supply-side factors are more important than the level of capital demand and that

[5]Dasgupta *et al.* (1982) argue that the social discount rate used in discounting public projects should be adjusted so that it is lower than that used in private projects. Sen (1982) also holds that it should be set lower than the private investment return.

[6]The real interest rate is derived by subtracting the depreciation from the marginal productivity of the capital. In this case, the method used to measure the depreciation is another issue in empirical analysis.

real interest rates are determined by the time preferences of consumers. However, time preference rate is subjective and varies from person to person; therefore, there is a considerable amount of debate on how to determine a single time preference rate that represents that of the whole society. In relation to the concept of the SDR, Lind *et al.* (1982) summarize the arguments and research contents of the literature, as outlined below.

First, the SDR is the social rate of the time preference, which is the rate at which society is willing to exchange consumption now for consumption in the future.

Second, the SDR is the consumption rate of interest, which is the rate at which individual consumers are willing to exchange consumption now for consumption in the future.

Third, the SDR is the marginal rate of return on investment in the private sector.

Fourth, the SDR is the opportunity cost of public investment, i.e., the value of private consumption and investment foregone as a result of that investment.

Fifth, the SDR is the risk price of public investment, which is related to the degree to which variation in the outcome of a public project will affect variation in the payoff from the nation's total assets.

Looking closely at these definitions, it can be seen that the first, second, third, and fourth cases are related to each other. Generally, economic agents apply discount rates for two reasons. First, consumption of one unit of goods at the present time provides greater utility than that of one unit of goods in the future. Second, in terms of investment, as opposed to consumption, one unit of goods is invested at present because it is regarded that it could produce more than one unit of goods tomorrow. Here, the first and second definitions refer to the rate of time preference in terms of consumption or savings and the third and fourth represent the rate of return in terms of investment.

Dasgupta and Pearce (1972) argue that it should reflect the temporal substitution of consumption and recommend using the social rate of time preference (SRTP) as the SDR. More specifically, the SRTP is expressed as follows,

$$\text{SRTP} = \rho + \mu \cdot g, \tag{1}$$

where ρ is the time preference rate, μ is the marginal utility elasticity of consumption (or the reciprocal of the intertemporal substitution or the replacement rate between periods of consumption) and g is the growth rate of consumption per person.

According to this method, the per capita consumption growth rate is relatively easy to derive from the data. Therefore, how accurately ρ and μ are estimated from the data in the calculation of SRTP is important. In the KDI guideline (2008), which is widely used as the basis of economic analyses of public projects, the SDR is derived using the SRTP.[7]

On the other hand, those who place greater emphasis on the investor's point of view argue for the use of the rate of return on investment as the SDR. In a complete

[7]Sen (1961), Marglin (1963a, 1963b), and Kay (1972), among others, advocate for the SRTP for the social discount rate.

market, the rate of return on investment is identical to the social opportunity cost of capital (SOCC).[8]

The SRTP and SOCC are perceived to be identical when the market is complete; however, in actuality, it is difficult to assume that these assumptions are established. Hence, the time preference rate and the investment return will generally differ from each other. Which is more desirable as the SDR, i.e., the rate of time preference or the rate of return on investment is an important issue.9 The SDR has been discussed since 1960, but there is a lack of a clear rationale with regard to the concept, and there are many difficulties in practical applications. Therefore, SDRs have been applied according to social agreement and necessity depending on the period and country. In recent years, rather than selecting one from between the SRTP and SOCC, the trend has been to determine the SDR using a weighted average, where the weights are determined from the foregone investment and consumption activities.[10]

B. *SDR vs. Private Discount Rate*

The question of whether the private discount rate can be used as the SDR has been the subject of research by many scholars.[11] In numerous economic and public policy models, a discount rate is determined in two ways. First, analysts use a discount rate to calculate the net present value of national economic benefits and costs for alternative policies or investments. To compute the social value of these benefits from a national perspective, one must discount using an appropriate rate for such a calculation; that is, it is necessary to use the social rate of discount. Second, these models occasionally use a discount rate in order to imitate the behavior of private sector investment, evaluating private investment alternatives by means of a discount rate equal to the required rate of return on investment in the private sector. A major open question is whether the social rate should be identical to the required rate of return on private investment.

Figure 2 shows the difference between the private rates and the SDRs.[12] Investment demand and savings are denoted by the solid lines of D and S, respectively, as a function of the interest rate. A higher interest rate is associated with lower investment demand because business opportunities which can guarantee profits exceeding the interest rate are rare. On the other hand, as the interest rate increases, the investment supply increases because the increase in the benefits of lending funds to investors through savings instead of consumption and consuming its return during the next time period will be higher than time preference rate. If the market is perfect and complete[13] and hence there is no market friction or

[8]Mishan (1967), Baumol (1968), and Diamond and Mirrlees (1971), among others, favor the SOC for the social discount rate.

[9]Baumol (1968) argues that the SRTP would be lower than the SOCC due to the presence of market distortions such as externalities and taxes, among others.

[10]See Spackman (2011) for further discussion on the social discount rates for European countries.

[11]See Eckstein (1957), Sen (1957, 1967, 1968), Feldstein (1964), Arrow (1966) and Baumol (1968).

[12]A part of the argument shown here is borrowed from Oak (2002).

[13]The market is referred to as complete when all the possible future states can be traded, while it is considered as perfect when sources of market friction, such as taxes and transaction costs, are absent.

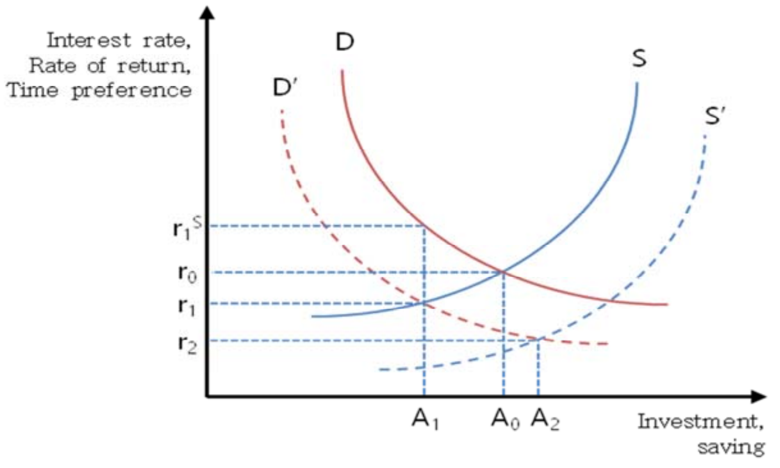

FIGURE 2. FINANCIAL MARKET EQUILIBRIUM

informational asymmetry, the market interest rate (r_0) determined as the rate of return on private investment and the time preference rate coincide with each other, and socially desirable savings and investment decisions (A_0) are made at that level. The market interest rate at this time will eventually become identical to the SDR.

However, if the market is incomplete, there is a gap between the market interest rate and the SDR. For example, if the government levies taxes on private investment, the after-tax return on investment becomes lower than the pre-tax return on investment such that the private investment return will be lower than the social investment return. In Figure 2, the imposition of taxes will cause the investment demand to shift from D to D'. Given that there is no change in the saving function, it is given as S, as before. The new investment demand curve and the saving curve are met at, and the market interest rate is determined at, r_1. The investment demand curve shifted to D' due to the imposition of taxes, but taxation is merely a transfer of wealth and is thus not effective from a social point of view. As the investment demand curve from the social point of view is still D, the return on social investment becomes r_1^s. Hence, the return on social investment exceeds the (social) time preference rate.

On the other hand, a gap between the SOCC and the SRTP can be observed even when there is a difference between the private time preference rate and the social time preference rate. For example, even if there is no market distortion due to taxation, the social saving function shifts down to S' when the social time preference rate is lower than the private time preference rate. The market interest rate is r_0 and the saving and investment meets at A_0 as in the original case, but the social time preference rate at this point is lower than the private time preference rate r_0. Thus, in this respect, there is a gap between the social investment return and the social time preference rate.

Can we determine which is larger among the social and private discount rates, let alone the magnitude? Many scholars have argued that the SDR should be lower than the private discount rate. Among others, Lind *et al.* (1982) suggested the following three rationales.

First, the state should be responsible not only for the current but also for future generations; hence, the discount rate should be selected considering the benefits of future generations (Super-responsibility argument).

Second, current civil servants or politicians are more interested in the welfare of future generations than their daily market activities (Dual-role argument).

Third, under a given preference system, members of the current generation are more likely to engage in collective agreements to save for future generations, even if they do not individually do so (Isolation argument).

Baumol (1968) argues that individuals do not place greater value on future benefits because they have a short-sighted view of social choice, and that in the case of public works, businesses of various sizes and forms operate at the same time. Hence, he claims that that the SDR will be lower than the private discount rate because it has the advantage of lowering the risk premium compared to private projects, as the government can reduce the risk by diversifying its investment opportunities.

C. *Weighted Average of the SDR*

It is difficult to determine a priori whether demand-side factors that emphasize time preference rates and supply-side factors that emphasize the marginal productivity of capital are more important when measuring SDRs. As equilibrium in an economy is determined by supply and demand, the discount rate that determines the social price of public investment will also be determined in terms of supply and demand. Hence, it would be natural to consider that the SDR should include both supply and demand factors. If the market is complete, the social and private SOCC and SRTP will then coincide with each other and one single SDR will exist in the economy. More often than not, we encounter incomplete market environments triggered by taxes or other types of market distortion.

Theoretically speaking, if the source of public investment comes from a reduction in consumption, the time preference rate should then be used, and if it comes from a reduction in investment, it is reasonable to use the return on investment for the SDR. However, it is difficult to determine the funding source of public investments in reality. Hence, we assume that part of the funding comes from a decrease in consumption and part of it from a decrease in investment. Under this assumption, the weighted average of the rate of return from private investment and the rate of time preference should be considered as reasonable measures of the SDR. The remaining task is to determine the weights. The weighted average of the SDR for a public investment project whose funding comes both from consumption and investment can be found by the following equation,

$$I_c SRTP + I_p SOCC = \left(I_c + I_p\right) WSDR,$$

where I_c and I_p denote the amounts of funding from consumption and investment financed for the public project, respectively, and WSDR indicates the weighted average of the SDR applicable to the project. Rewriting the equation by isolating the WSDR, the following equation is obtained:

$$\text{WSDR} = \frac{I_c}{I_c + I_p} SRTP + \frac{I_p}{I_c + I_p} SOCC$$

$$= w_c SRTP + w_p SOCC$$

Here, $w_c = \frac{I_c}{I_c + I_p}$ and $w_p = \frac{I_p}{I_c + I_p}$. As it is difficult to distinguish the incremental monetary contributions of consumption and investment for the project, we apply the ratio of the total use of funds between household and corporate sectors to compute the weights.

III. Empirical Models

As there is no single model that can cover all sorts of views on the SDR, we construct various empirical models to estimate the SDR and propose the weighted average of these estimates.[14] We start by estimating a production function to find rate of return on investment. This can be regarded as estimating the demand schedule in the loanable funds market. We then estimate the rate of time preference based on the Euler equation. This can be seen as the supply schedule in the loanable funds market. Finally, we present the weight average of the two, where the weight is given by the total funds used by households and firms in flow of funds data collected by the Bank of Korea.

A. *Marginal Productivity Using a Production Function*

In the following paragraphs, we attempt to estimate the production function of Cobb-Douglas, composed of private and social overhead capital. This follows Doi and Ihori (2009), as shown below.[15]

$$Y_t = e^{A_t + \varepsilon_t} K_t^{\alpha_1} G_t^{\alpha_2} L_t^{\beta}$$

[14]Shin *et al.* (2013) estimate real interest rates using a production function approach. They propose that the real interest rate was 2.6% in 2006 ~ 2010 but that the interest rate subsequently will fall and then reverse its course and rise after 2071.

[15]It is possible to consider adding the lagged variables of capital in the estimation using the production function. However, as the capital stock has accumulated with past investments, the explanatory power of the additional a time lag is not high. Moreover, additional constraints should be added in order to allow non-negative productivity parameters, which will lower the efficiency of the estimates. Thus, we adopt the estimation model of Song (2016).

In this equation, Y_t is the real GDP at time t, A_t denotes the technological progress, L_t is the economic activity population at time t, K_t represents the private capital stock at time t, and G_t denotes the social overhead capital at time t. In addition, ε_t is the measurement error or production function shock unobserved by econometricians.[16]

Dividing both sides of the production function by the economically active population and taking the log, we have the following:[17]

$$\ln y_t = A_t + \alpha_1 \ln k_t + \alpha_2 \ln g_t + \varepsilon_t \tag{2}$$

Typically, macroeconomic variables are known to have unit roots. Therefore, it is common to take the difference and use first-order residuals rather than the level of these variables,

$$\text{dln } y_t = dlnA_t + \alpha_1 \text{dln} k_t + \alpha_2 \text{dln} g_t + \varepsilon_t - \eta\varepsilon_{t-1}, \tag{3}$$

where η implies the MA (1), or the cross-autocorrelation of the errors. The cross-autocorrelation in the error term occurs due to differencing. In this case, the marginal productivity of private and social overhead capital can be calculated using the equation below.

$$MP_{K,t} = \frac{\partial Y_t}{\partial K_t} = \alpha_1 \frac{Y_t}{K_t}, \quad MP_{G,t} = \frac{\partial Y_t}{\partial G_t} = \alpha_2 \frac{Y_t}{G_t} \tag{4}$$

The Cobb-Douglas function is most widely used as a primary method to determine the productivity of capital, as it is easy to apply in an empirical analysis. Capital can produce outcome at the cost of a fraction of it, which is called the depreciation rate. Therefore, in order to determine the rate of return from the investment, one needs to subtract the depreciation rate from marginal productivity;

i.e.,

$$r_{i,t} = MP_{i,t} - \delta_i, \ \ i = K, G, \tag{5}$$

where $r_{i,t}$ is the return on the investment of capital and δ_i is the depreciation rate of the capital.

B. *Time Preference Rate using the Euler Equation*

In order to estimate the SRTP, we need the values for ρ and μ, as shown in

[16]Since Cobb-Douglas is a production function, it is reasonable to regard Y_t as the real output rather than the real GDP, which is the sum of the added value. However, because the production function covered in this paper does not include intermediate goods, Y_t indicates the real GDP.

[17]Variables divided by the economically active population are shown in lower case.

Eq. (1). The conventional method is to calibrate those values separately from different sets of data and combine them to estimate SRTP afterwards; hence, this method is subject to the question whether those values are consistent with each other. In the following paragraphs, we show that these values can be estimated jointly from the Euler equation.

Consider the Ramsey growth model, which that maximizes a typical household's life-time utility under the intertemporal budget constraint,

$$\max \int_0^\infty U(c_t) e^{-\rho t} dt$$
$$\text{s.t. } \dot{k}_t = f(k_t) - \delta k_t - c_t$$

where $U(\cdot)$ is invariant over time with $U'(\cdot) > 0$ (i.e., the marginal utility for consumption is positive) and $U''(\cdot) < 0$ (i.e., a decrease in the marginal utility). In addition, ρ is the utility discount rate reflecting the pure time preference, δ is the capital depreciation rate, c_t denotes consumption at time t, $f(\cdot)$ is the production function, and $\dot{k}_t$ represents the net investment at time t. The first-order condition of utility maximization is summarized as follows.

(6) $$U'(c_t)\big(f'(k_t) - \delta\big) + U''(c_t)\dot{c}_t - \rho U'(c_t) = 0$$

where, $\dot{c}_t$ represents the changes in consumption at time t. If the utility function takes the form of CRRA (constant relative risk aversion), the above equation can be simplified as follows,

(7) $$r = f'(k_t) - \delta = \rho + \mu g$$

where r is the interest rate on savings and $\mu = \frac{U''}{U'}c$ is the elasticity of marginal utility on consumption, or the reciprocal of the rate of substitution over time. Let $g = \dot{c}_t / c_t$ represent the growth rate of per-capita consumption. The above formula essentially takes a form identical to that of the SRTP, and if we have the discount rate for time (ρ) and the marginal rate of substitution for time (μ), we can derive the discount rate based on time preference with a reasonable assumption about the future consumption growth rate. In order to estimate the model, the utility maximization problem is set up under discrete time rather than continuous time. That is, the representative household solves the problem of maximizing the lifetime utility function under uncertainty, as follows.

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t), \quad 0 < \beta < 1$$

$$C_t + \sum_{i=1}^{k} P_{it} B_{it} = \sum_{i=1}^{k} (1 + r_{it}) B_{it-1} + Y_t$$

In these equations, β is a discount factor with the relationship $\beta = \frac{1}{1+\rho}$ with discount rate ρ. P_{it} and B_{it} denote the price and quantity of an asset i at time t, respectively, and Y_t represents non-asset income at time t. Under the given budget constraint, the necessary conditions for maximizing one's lifetime utility are expressed by the Euler equation:

(8) $$U'(C_t) = \beta E_t\left[(1 + r_{i,t+1}) U'(C_{t+1})\right], \quad i = 1, \ldots, k$$

For the empirical analysis, the introduction of an explicit utility function is required. In this case, $U(C_t) = \frac{C_t^{1-\mu}}{1-\mu}$ is used, where the degree of relative risk aversion is constant. Substituting this equation into the Euler equation, we have the following equation:

(9) $$E_t\left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\mu}(1 + r_{i,t+1}) - 1\right] = 0$$

This equation shows that there is a close relationship between asset returns and the consumption growth rate. Using this, we can derive the discount rate reflecting the time preference by estimating β and μ. The quarterly discount factor (β) can be transformed into the annual discount rate, ρ, and can be derived using the following relationship.[18]

$$\frac{1}{1+\rho} = \beta^4$$

Finally, the final time preference rate, SRTP, can be determined from Equation (1).

[18]As the Euler equations are estimated using quarterly data, we need to quadruple β to back out the annualized discount rate.

IV. Estimation Results

A. *Data*

In order to examine the marginal productivity of capital through the Cobb-Douglas production function, we used annual data of 1970-2013 for private capital stock and public capital stock on the national balance sheet filed by the Bank of Korea. For the estimation of the Euler equations, the data on per capita consumption, CPI inflation, treasury bond yields, corporate bond yields, and stock returns are available from the second quarter of 1995. Therefore, in the analysis, the quarters from 1995 - Q2 to 2016 - Q1 were used. Table 1 shows the basic statistics of the data used in the analysis.

TABLE 1—SUMMARY STATISTICS

(UNIT: MILLION WON, %)

Variables	Obs.	Mean	Median	S.D.	Min	Max
Real GDP per economically active population	44	22.882	21.572	12.499	6.147	44.010
Private capital per economically active population	44	86.316	70.581	63.286	10.163	197.545
Social overhead capital per economically active population	44	30.201	22.931	22.932	3.422	70.602
Household consumption growth rate	85	0.835	0.797	3.359	-13.693	9.121
Household consumption (seasonal adjusted) growth Rate	85	0.821	0.945	2.033	-13.792	3.952
KOSPI index return	85	2.093	0.836	16.865	-41.848	81.252
CPI growth rate	85	0.759	0.664	0.756	-0.421	5.257
3-year KTB interest rate	84	5.943	4.800	3.554	1.534	16.340
3-year corporate bond (AA) interest rate	85	6.878	5.490	3.884	1.980	20.710

Note: Public capital data is only available as the annual frequency.

Source: Statistics Korea, Bank of Korea.

B. *Discount Rate Estimation Using a Production Function*

Table 2 shows the estimation results of the Cobb-Douglas function.[19] The production elasticity of private capital is 0.2774, the elasticity of social overhead capital is 0.15, and both elasticity rates are statistically significant at the 10% level. The sign of the coefficient of MA, on the other hand, met the expectations but the statistical significance was low.

Previous studies have shown that the elasticity of social overhead capital is 0.245 according to an analysis using data from 1968 to 2000. Another study found it to be 0.302 (Ryu, 2005b). This difference stems from the use of the public capital of the government sector in that study. On the other hand, Ryu (2008) re-estimated the elasticity of production using the capital stock of the government sector from 1968 to 2005, finding that the elasticity is 0.439 for OLS and 0.277 for 2SLS. In Kang (2006), the elasticity of public capital was estimated using macroeconomic data from 1970 to 2004 with a production function approach. The elasticity of

[19]The test results of the validity of constant returns to the scale production function are included in Appendix 1.

TABLE 2—LIKELIHOOD FUNCTION ESTIMATES

Variable	Coefficient	Std. Err	p-value
DL_PK	0.2774	0.1426	0.0547
DL_GK	0.1501	0.0001	0.0000
MA(1)	-0.0385	0.1777	0.4186
constant	0.0159	0.0107	0.0987

Note: DL_PK denotes the logarithmic difference of the private capital/economically active population, DL_GK is the logarithm of the social overhead capital/economically active population, and MA (1) is the estimate of $-\eta$.

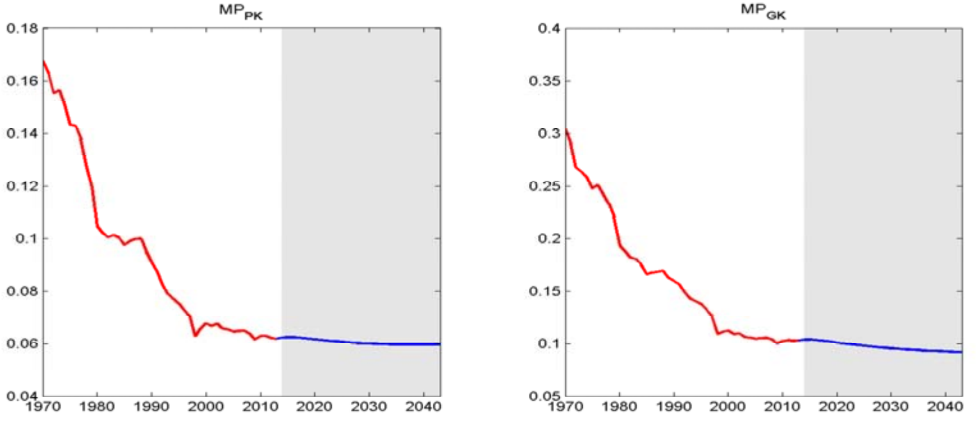

FIGURE 3. MARGINAL PRODUCTIVITY TREND AND FORECASTS OF PRIVATE AND SOCIAL OVERHEAD CAPITAL

Note: The shaded areas represent the period in which the marginal productivity of capital is predicted (2014-2043).

public capital at the regression using level variables was as high as 0.43. The elasticity of public capital ranges from -0.0075 to 0.1858 when using first-order differencing to make the variables stationary. The social overhead capital estimated in this paper is lower than that of Ryu (2005a, 2005b, 2008), but the value exists within the interval indicated in the study by Kang (2006). Moreover, while the capital stock derived from the permanent inventory method has been used in most studies thus far, the data employed in the current work is national balance sheet capital stock data, where the depreciation rate is computed based on the age-price function of the asset. This also likely contributes to the differences in the elasticity estimates between the current work and other studies. In addition, the period covered by the data and the estimation model are other factors contributing to the difference.

Based on the estimation results, the marginal productivity of private and social overhead capital can be easily calculated. These results are shown in Figure 3 and Table 3.[20] The marginal productivity of private capital, which had exceeded 16% in the early 1970s, reached 6% in 2000. In the early 1970s, marginal productivity

[20]The future economic activity population, per capita output, private capital stock, and social overhead capital stock, which are necessary to determine the marginal productivity, are derived using the VAR. Estimation results of the VAR model are included in Appendix 2.

TABLE 3—MARGINAL PRODUCTIVITY FORECASTS OF PRIVATE CAPITAL (MPPK) AND SOCIAL OVERHEAD CAPITAL (MPGK)

Years Ahead	Year	MPPK	MPGK
1	2014	0.0622	0.1035
2	2015	0.0623	0.1036
3	2016	0.0622	0.1032
4	2017	0.0621	0.1027
5	2018	0.0619	0.1021
10	2023	0.0609	0.0988
15	2028	0.0601	0.0961
20	2033	0.0597	0.0941
30	2043	0.0597	0.0915

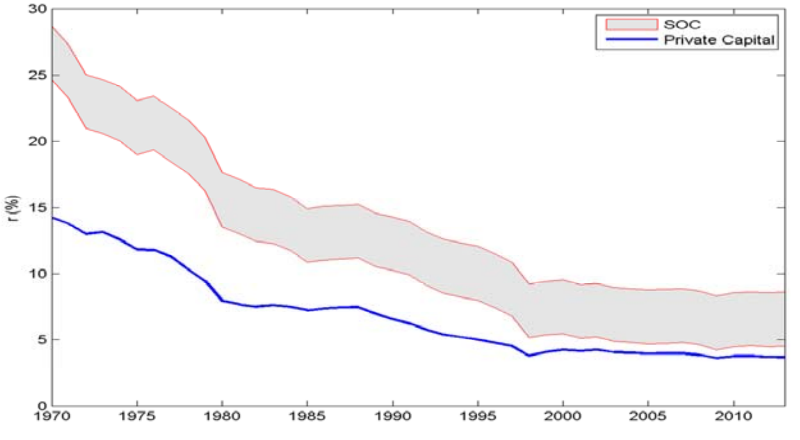

FIGURE 4. SOCIAL OVERHEAD CAPITAL AND PRIVATE CAPITAL DISCOUNT RATE

exceeded 30% due to insufficient social overhead capital, but it has recently declined to 10%. Although the productivity coefficient of private capital is twice as high as that of social overhead capital, the marginal productivity of private capital is lower than that of social overhead capital due to the difference in the size of the capital stock.

On the other hand, depreciation rates should be subtracted to derive the return on investment of capital. There is little research on appropriate depreciation rates for social overhead capital, while private capital generally uses 2.5% per annum. Cho *et al.* (2012) discussed the depreciation rates for the social overhead cost, but their study is limited to only certain selected sectors. Hence, in this paper, we apply the depreciation rate of 2.5% for private capital, as is done in most conventional studies. For social overhead capital, we attempt to minimize the arbitrariness involved in choosing depreciation rates by presenting the band rather the specific value of the depreciation rate, while the maximum (water and sewage: 5.7%) and minimum (rail: 1.6%) values of the depreciation rate are used to derive the return on social overhead capital. Figure 4 presents the return on investment of the private and social overhead capital net depreciation rates. Private investment returns have fallen to 3% since 2005. On the other hand, in the case of social overhead capital, under the minimum depreciation rate, the return on investment is 8.6% as of 2013, while under the maximum depreciation rate, the return on investment of social overhead capital is 4.5%.

C. *Estimation of the Discount Rate Using the Euler Equation*

Due to the nonlinear nature of the Euler equation used to estimate these parameters, we employ the GMM method. Compared to MLE, GMM does not require distributional assumptions other than the moment conditions, and this is a required condition to estimate the Euler equation. In order to implement GMM as proposed by Hansen (1982), it is necessary to derive the residual equation from the Euler equation. The residual term from the Euler equation, which is u_t, can be expressed as follows:

$$u_t = f\left(X_{t+1}, b\right) = \left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\mu}\left(1+r_{i,t+1}\right)-1\right] \quad (10)$$

Suppose that there are m parameters to be estimated when there are n assets to be invested; then, $f: R^{n+1}\times R^m \to R^n$. According to the Euler equation, we have $\mathrm{E}_t\left[u_{t+1}\right]=0$. In order to use GMM, a set of instrumental variables should be introduced. Here, the following set of instruments in line with Hansen and Singleton (1988) is used.

$$z_t = \left[1, \frac{C_t}{C_{t-1}},\ r_{t-1}^f,\ r_{t-1}^e,\ r_{t-1}^b\right]$$

In this equation, r^f denotes the three-month government bond yield, r^e is the stock price return, and r^b is the three-month corporate bond yield. The orthogonalization conditions using these instruments are as follows,

$$E\left[h\left(X_{t+1}, Z_t, b\right)\right]=0$$

$$h\left(X_{t+1}, Z_t, b\right) \equiv f\left(X_{t+1}, b\right),$$

where $b=\left[\beta,\mu\right]$. If the residual equation is defined as $g_0 = E\left[h\left(X_{t+1}, z_t, b\right)\right]$, then $g_0\left(b_0\right)=0$, where the sample analog is simply as follows:

$$g_T\left(b\right)=\frac{1}{T}\sum_{t=1}^{T} h\left(X_{t+1}, Z_t, b\right)$$

With the sample residual equation defined above, we can establish the following quadratic function and minimize it with respect to b.

$$J_T(b) = g_T(b)' W_T g_T(b)$$

Here, W_T is a weighting matrix, which can be derived using an asymptotic variance-covariance matrix.

$$W_T = \left[\sum_{j=-k+1}^{K-1} \frac{1}{T} \sum_{t=1+j}^{T} h(X_{t+n}, Z_t, b_t) h(X_{t+n-j}, Z_{t-j}, b_t)' \right]^{-1}$$

The estimated b_T is a consistent estimator. Additionally, under this coefficient, the objective function has an asymptotic chi-square distribution with the degree of freedom being the difference between the number of moment equations (q) and the parameter to be estimated (m),

$$T \cdot J_T(b_T) = T \cdot g_T(b_T)' W_T g_T(b_T) \to^d \chi^2(q-m) \quad (11)$$

where T denotes the number of observations. In order to run the estimate using actual data, the value of W_T is necessary to estimate b. Hence, a two-step estimation method is used. In the first step, we set $W_T = I$ and estimate b. In the second step, we compute W_T based on b as estimated in the first step. The objective function is then adjusted using W_T from the last step, after which b is finally re-estimated.

The resulting estimates of (β, μ) using this method are shown in Table 4. β and μ are estimated as 0.9944 and 0.7644, respectively. The p-values are significantly low for both values, indicating statistical significance. On the other hand, over-identification tests that examine the validity of additional instrument variables were rejected at the 5% significance level, suggesting that the moments from the additional instrument variables were not significant.

The discount rates can be derived based on these estimation results, as shown in Table 5. When the growth rates are known *a priori*, the interest rate in the steady state is determined as $r = \rho + \mu g$, where $\rho = \beta^{-4} - 1$. Given that we have already found β and μ by means of GMM estimations, we can derive the corresponding values of r by changing g. Hence, to recover the discount rates, we only need to make assumptions about the growth rates. In this paper, we

TABLE 4—GMM ESTIMATES

Variable	Coefficients	Std. Err	p-value
β	0.9944	0.0013	0.0000
μ	0.7644	0.0032	0.0000
Over-id Test (Hansen's J test)		64.6604	
x^2 (0.05, df=14)		22.3620	

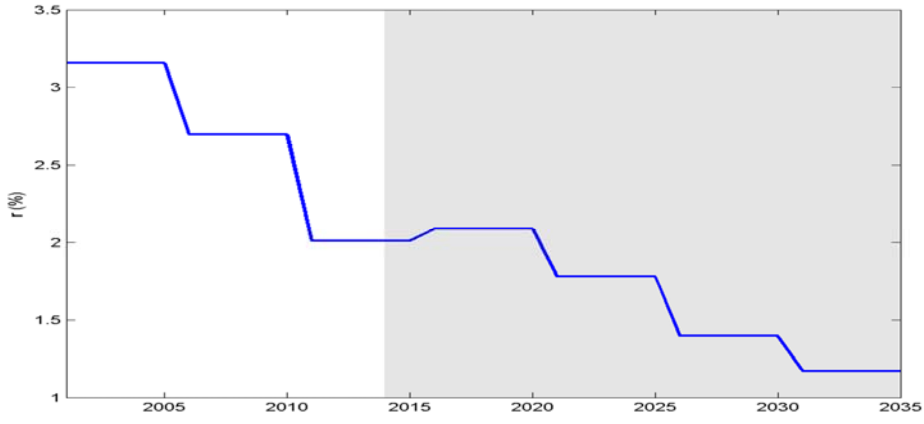

FIGURE 5. DISCOUNT RATE (r) BASED ON TIME PREFERENCE

TABLE 5—DISCOUNT RATE FORECASTS

Years	Potential growth rate*	r(%)
2001~2005	4.1	3.1567
2006~2010	3.5	2.6981
2011~2015	2.6	2.0102
2016~2020	2.7	2.0866
2021~2025	2.3	1.7809
2026~2030	1.8	1.3987
2031~2035	1.5	1.1694

Note: Kwon and Cho (2014).

attempt to compute the discount rate using the potential growth rate of Korea until 2035 as presented by Kwon and Cho (2014). As a result, the discount rate reflecting the time preference was 3.2% in 2001 ~ 2005, and the discount rate decreased as the potential growth rate declined for every subsequent year. This rate dropped to 1.2% in the period of 2031~2035. These results are shown in Figure 5.

D. *Weighted Average Discount Rate*

In this case, we want to derive the weighted average SDR of the investment return of the enterprise and the time preference rate of the household. The weights used here are derived from the Bank of Korea's financial circulation table and the proportion of corporate fund operations (see Table 6 below). Of course, the weights presented here are only one from among the sets of selectable weights and are not held to be perfect. However, as economic entities allocate or adjust investment funds as usefully as possible, it would be preferable to use weightings based on the fund operation scale if it is necessary to weigh the different discount rates of private enterprises and households, as this ensures the use of a good proxy for foregone consumption and investment. The weighted average discount rate derived from these weights is shown in Figure 6.[21] Using the weighted average of private

[21]After 2016, the same weighting is used for 2015.

TABLE 6—SHARE OF HOUSEHOLD AND CORPORATE FUND OPERATIONS

(UNIT: BILLION WON)

Year	Private firm	Households and NPO	Private firm weight (%)	Households weight (%)
2010	86,987.4	142,016.0	38.0	62.0
2011	67,365.1	161,626.8	29.4	70.6
2012	55,425.5	127,083.8	30.4	69.6
2013	84,773.7	153,045.0	35.6	64.4
2014	96,411.8	171,782.5	35.9	64.1
2015	92,368.6	226,855.3	28.9	71.1

Note: ECOS, Bank of Korea.

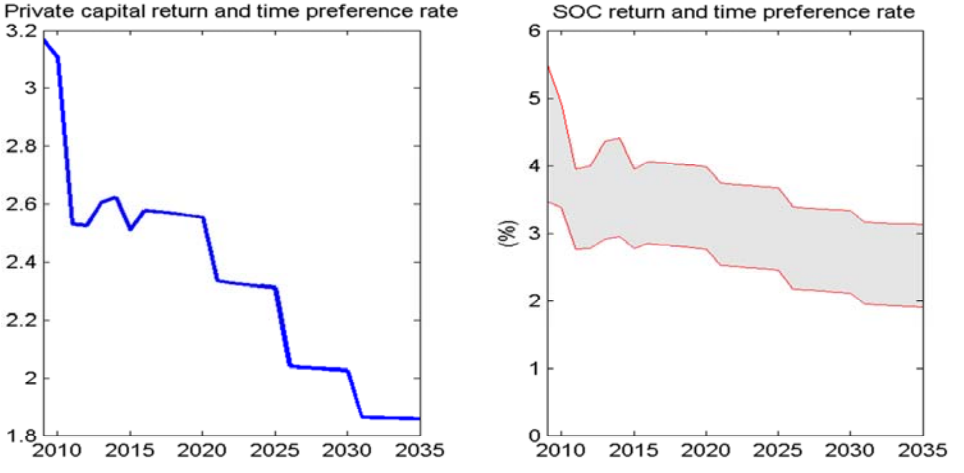

FIGURE 6. WEIGHTED AVERAGE OF THE INVESTMENT RETURN AND TIME PREFERENCE RATE

capital investment returns and time preference rates, it falls from 2.5% in 2015 to 1.85% in 2035. The weighted average between social overhead capital investment returns and time preference rates is expected to be adjusted from 2.8% to 3.9% in 2015 to 1.9% to 3.1% in 2035.[22]

V. Conclusion

In this paper, the concept of the SDR, which is the most important key parameter in any analysis of the economic feasibility of a public investment project, is discussed and the social preference rate is estimated using data based on a theoretical model considering the investment return rate and the time preference rate.

The estimation results are summarized as follows. The return on investment from private capital has remained at approximately 3% since 2005, and the return on investment of social overhead capital ranges from 4.5% to 8.6% depending on

[22]Interested readers can request the specific results.

the depreciation rate. On the other hand, when the time preference rate is used, the discount rate in the early 2000s is 3.2%, and this rate declines when the potential growth rate decreases. Over the long term, the discount rate is reduced to 1.2% in 2030. Although the results differ somewhat depending on the model and assumptions used in the analysis, the discount rate is usually in the range of 3.0 ~ 4.5% and is expected to fall below 3% over the longer term. This suggests that a SDR of at least 1% p must be downgraded from the standard rate which is currently used in public projects.

As the nature of public projects reflects the investment and economic conditions, it is desirable for the SDR also to change over time. However, in practical terms, if different SDRs are used each year, the profitability of the same project will change from year to year. Moreover, if economic conditions or the investment environment change over a certain period of time, an adjustment of the SDR becomes inevitable. The purpose of this study is to estimate the SDR in the current situation by reflecting policies and practical demand levels[23]. In addition to financial benefits and costs, there are no clear criteria with regard to setting the opportunity cost in an economic analysis of a public works project when non-monetary benefits and costs should be added. Under this situation, practitioners' direct and indirect experience and areas of specialty related to the recognition and measurement of benefits and costs of the candidate project can become a non-negligible factor in determining which discount rate will be applied to the public project. Hence, it is important to understand that there are inherent limitations when attempting to pin down a single SDR and conduct robustness checks by applying different values of the SDR to determine the sensitivity of the benefit-cost ratio to the discount rate. Most researchers agree with the necessity of recalibrating the SDR level, but researchers are likely to have different viewpoints in relation to the specific scope of adjustment of the incumbent discount rate. However, I hope that this article contributes to the creation of a platform for academic and practical discussions of these topics.

APPENDIX

A1. *Test of the Constant Returns to Scale Production Function*

In this section, we conduct a test to verify whether the return to scale is constant, i.e., CRS. If the production function is not CRS, then we have $\alpha_1 + \alpha_2 + \beta \neq 1$. Therefore, even if both sides are divided by the economically active population, the population does not disappear from the equation; therefore, equation (3) becomes

$$dln\, y_t = A + \alpha_1 dlnk_t + \alpha_2 dlng_t + \gamma dlnL_t \varepsilon_t - \eta \varepsilon_{t-1},$$

[23]The news search hits on public projects stand at 116 for 2016 compared to 59 for 2010 when public project and KDI are used as search keywords. When one uses public project as a single keyword, the hits stand at 655 in 2016, almost doubled from the 334 hits for 2010 (www.kinds.or.kr). We believe this reflects the policies and social demand levels for the SDR.

TABLE A1—LIKELIHOOD FUNCTION ESTIMATES

Variable	Coefficient	Std. Err	p-value
DL_PK	0.2054	0.1439	0.1017
DL_GK	0.1452	0.0002	0.0000
DL_LR	0.4771	0.2999	0.0814
MA(1)	-0.0705	0.1769	0.3519
constant	0.0105	0.0108	0.1826

Note: DL_PK is the logarithmic difference of private capital / economy population, DL_GK is social overhead capital / economically active population, DL_LR is the logarithm of economic activity population, and MA (1) denotes the MA term, $-\eta$.

where $\gamma = \alpha_1 + \alpha_2 + \beta - 1$. Therefore, we can check whether γ is statistically significant through MA(1)-MLE, and the validity of the CRS assumption can be examined. The estimation result is shown in Table A1. The estimate of the logarithmic population is 0.4771, which is quite high, but the significance probability is 0.0814, which is rejected at the statistical significance level of 5%.

The magnitude of the parameter is economically too significant to ignore the effect of the economically active population. We argue that the population variable reflects the characteristics of human capital rather than simply the labor force itself.

A2. *Forecast Using the VAR Model*

In order to predict the marginal productivity trend of capital, we estimate the following 3-variate VAR model with the real GDP (y_t), private capital stock (k_t) and social overhead capital stock (g_t),

$$X_t = \mu + \pi_1 X_{t-1} + \pi_2 X_{t-2} + \cdots + \pi_p X_{t-p} + \epsilon_t,$$

where $X_t = \begin{pmatrix} \Delta \ln y_t \\ \Delta \ln k_t \\ \Delta \ln g_t \end{pmatrix}$, μ is a constant vector of 3 × 1, $\{\pi_i\}_{i=1}^{p}$ is a coefficient matrix of 3 × 3, and ϵ_t represents a residual vector of 3 × 1. The results of the VAR model estimation are shown in Table A2.

TABLE A2—VAR ESTIMATES

Dependent Variable	$\Delta \ln y_t$	$\Delta \ln k_t$	$\Delta \ln g_t$
$\Delta \ln y_{t-1}$	0.003	0.124	0.064
$\Delta \ln k_{t-1}$	-0.316	0.988***	0.353*
$\Delta \ln g_{t-1}$	0.605*	-0.217	0.468**
Constant	0.024*	0.009	0.008

Note: *** p<0.01, ** p<0.05, * p<0.1 The optimal lag order is set to 1 based on AIC.

A3. *Estimated Parameters of the Marginal Utility Elasticity of Consumption*

Table A3 summarizes the previous empirical results for the marginal utility elasticity of consumption as required to derive the SDR using the Ramsey growth model.

TABLE A3—MARGINAL UTILITY ELASTICITY OF CONSUMPTION ESTIMATES

Research	Method	μ
Korea Development Institute (2008)	Savings behavior	0.54~1.16
Min (2016)	Savings behavior	0.02~0.29
	Structure of personal income tax rate	0.85~1.18

In order to determine μ, previous studies mainly used individual saving behavior (Scott, 1989). Calibrating μ to satisfy the equation below, we can find the marginal utility elasticity of consumption,[25]

$$\frac{S}{Y}=\left[\left(\frac{1}{\mu}\right)(r-\rho)-y\right]/[r-y]$$

where $\frac{S}{Y}$ is the saving rate, r is the real interest rate, ρ is the utility discount rate, and y is the expected growth rate of income.

Because the saving behavior method calculates μ such that it meets the stipulations of the equation based on the saving rate, there is a problem when attempting to find a representative value of the saving rate which has relatively large variation and a trend change. In contrast, the Euler equation approach adopted in this paper is more advantageous in that it can find a more stable μ to realize a parameter consistent with market data and can jointly estimate the marginal utility elasticity and time discount rate.

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[25]See Pearce and Ulph (1999) for an additional discussion.

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