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The Shadow Price of Capital: Accounting for Capital Displacement in Cost Benefit Analysis

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Introduction

Circular A-4 (OMB 2003), a guidance document that provides recommendations for federal agencies conducting benefit-cost analysis (BCA), recommends the use of two discount rates to adjust estimated future costs and benefits to present-day equivalents: 3 percent and 7 percent. The 3 percent rate is meant to reflect the discount rate applicable to consumers (i.e., households), whereas the 7 percent—which we refer to as the investment rate of return—is meant to reflect the fact that costs may displace capital investment that has a higher rate of return than the consumption rate. However, Circular A-4 notes that the analytically preferred method to account for this higher rate of return is rather to use the "shadow price of capital" (SPC) approach, in which costs displacing capital investments are converted to consumption-equivalent values which can be directly compared; then, all costs and benefits are appropriately discounted at the consumption rate.

Nonetheless, this analytically preferred SPC approach is rarely used in practice. Instead, federal analysts typically discount all costs and benefits at the investment rate, currently set at 7 percent by Circular A-4, with the intention that the simple use of the investment rate serves as a simplified approximation of the SPC approach. In this article, we explain why that approach is generally incorrect and how it can yield extremely incorrect estimates of the costs and benefits of policies with long-lived impacts such as climate change.

While the use of an investment rate as the discount rate is common practice by federal analysts, recent literature has demonstrated that such an approach is only conceptually consistent with the analytically preferred SPC method under very restrictive and unrealistic conditions that are almost never satisfied (Li and Pizer 2021). The reason is that discounting at an investment rate ignores the differences between the time pattern of capital returns compared to the time pattern of benefits.

Discounting at the investment rate effectively asks whether a government regulation has a higher net benefit than the opportunity cost of foregone capital, which ignores those alternative time patterns. Even if two options have the same internal rate of return, the value to households will differ if the time pattern differs.

This implies that the longstanding approach of using a 7 percent discount rate is typically inconsistent with the analytically preferred approach of the SPC. Furthermore, the degree of inaccuracy embedded in using a 7 percent discount rate tends to compound the longer is the timeframe of the policy being evaluated; it is therefore particularly flawed, for example, for evaluating actions with long-term consequences, such as from actions that reduce greenhouse gas emissions.

This study explains how to move beyond the erroneous but common practice of applying a 7 percent discount rate to address concerns about capital displacement. Instead, we show how the conceptually superior shadow price of capital approach is simple to implement in practice, would not involve major changes in analytical

procedures, and would in fact simplify federal cost benefit analysis by dispensing with the use of multiple internally inconsistent discount rates within a given BCA. We demonstrate how one would implement this by re-evaluating the final regulatory impact analysis (RIA) for the 2015 Clean Power Plan using the shadow price of capital framework under Circular A-4's recommended 3 percent consumption discount rate. This demonstrates that the SPC approach would be simple to implement, account for concerns about capital displacement without resorting to the mistaken 7 percent discount rate approach, while also yielding results not dramatically different from those reached by recently conducted RIAs.

The Analytically Preferred Method is the Shadow Price of Capital, which Reflects the Impact and Duration of Capital Displacement

Since the shadow price of capital approach is preferred to the simple application of the investment rate to benefits, the natural question is what an appropriate shadow price is for use in benefit-cost analysis. The shadow price of capital, which reflects value lost from displaced capital investment, depends on how long such capital remains displaced in the economy into the future. The degree of such persistence in displacement is determined by broad economic equilibrium dynamics including depreciation and savings, suggesting that the SPC should be guided by macro-derived models of optimal savings and investment. Li and Pizer (2021) present such a model, demonstrating that the SPC reflecting the degree of permanence of capital displacement depends on four parameters:

(i) μ, the depreciation rate of capital, which determines how quickly displaced capital would have decayed over time anyway;

(ii) s, the savings rate, which replenishes capital over time;

(iii) r_i, the investment rate of return, which determines the annual consumption lost per dollar of displaced capital; and

(iv) r_c, the consumption rate of return, which converts lost investment returns to consumption-equivalent present values.

Li and Pizer (2021) and Pizer (2021) present the following analytical expression for the shadow price of capital as a function of these parameters:

$$SPC = \frac{(1-s)(r_i+\mu)}{r_c+\mu-s(r_i+\mu)}$$

Using reasonable ranges for these parameters, Pizer (2021) suggests an SPC value of 1.2. A range of sensitivities around inputs to this equation suggest an upper bound value of no more than 1.6.

A Simple Sensitivity Approach to the Shadow Price of Capital, with an Illustrative Example

Once an estimate of the shadow price of capital is identified, its application is straightforward: simply adjust any capital-displacing costs (or benefits) in any year upwards by multiplying by a factor equal to the shadow price of capital. Since the shadow price of capital converts capital costs into consumption equivalents, all costs and benefits can then be directly compared and discounted at the consumption discount rate. This

allows analysts to dispense with the common but contentious approach of using the investment rate and avoid using multiple different discount rates in a single analysis.

The SPC sensitivity approach is both simpler and analytically more correct than the current approach of using a 7% investment rate and can be implemented using currently available information. Moreover, the SPC sensitivity approach is less biased in its assumptions with regard to whether costs displace investment or benefits augment investment—the latter possibility being underappreciated (Li and Pizer 2021). For example, reduced damages from climate change may prevent destruction of long-lived assets, such as coastal infrastructure, or reduced health costs may enable households to save more.

Specifically, when it is not clear whether particular costs or benefits category displaces capital versus investment, the SPC sensitivity approach involves simply examining two extreme cases—one that assumes all costs displace capital, and another than all benefits augment capital. These two extremes would bound a central case that assumes all costs and benefits fall on consumption (consistent with the historically used 3% discount rate case). In all cases the discount rate used is the consumption rate.

To demonstrate the simplicity of the SPC sensitivity approach, we show how analysts could have implemented the SPC in the regulatory impact analysis for the 2015 Clean Power Plan (CPP). That plan somewhat confusingly compared costs and benefits calculated under multiple different discount rates, raising concerns about internal validity. The SPC approach would avoid such concerns while nonetheless accounting for the issue of capital-displacement.

Table 1 shows a re-creation of the 2015 CPP rule benefit-cost analysis. We show the net benefits calculation using the snapshot approach for three specific years—2020, 2025, and 2030—as was done in the original RIA. While the original RIA mixed 3% and 7% discount rates, we dispense with the need for the 7% discount rate by accounting for the potential for capital displacement using the shadow price of capital. This greatly simplifies the net benefits Table below. The main panel of the original table from the CPP RIA is shown in Figure 1 for reference, illustrating its much more complex nature.

Rather than the six columns in the original table representing benefits at consumption and investment discount rates, we simply add new rows representing benefits, costs, and net benefits using the shadow price of capital approach. In this case, the application of the shadow price of capital involves scaling up compliance costs in each year by a factor of 1.2X (i.e., a 20% premium), under the assumption that all costs displace capital, and then using the consumption rate to discount all costs and benefits. In this application, the compliance costs originally estimated by EPA were $2.5, $1.0, and $8.4 billion in years 2020, 2025, and 2030. The 20% premium on these costs adds $0.5, $0.2, and $1.68 billion in costs from displaced capital in each of those years.

The application of the SPC changes net benefits by a relatively small amount in this context, for example changing net benefits in 2030 from the range of $26 to $46 billion to $24 to $44 billion—a reduction of about $2 billion. For reference, and as can be seen by comparison to Figure 1, this has a similar effect to applying the higher 7% discount rate to air quality health benefits alone, which reduces those benefits by a similar amount of about $1 to $3 billion in 2030.

In the other sensitivity case, we apply the SPC on the benefits side of the ledger to account for the potential capital impacts of environmental improvements, such as reduced mortality bolstering the value of human capital. However, we do not apply the SPC to climate benefits to convert to consumption equivalent values because those climate benefits are already in consumption-equivalent terms. This increases estimated net benefits from the range of $26 to $46 billion to $28 to $52 billion.

Table 1. Monetized Benefits, Compliance Costs, and Net Benefits of Clean Power Plan, Under 2015 RIA and Updated SPC Approach, 3% Discount Rate

		Value (billions of 2011$)			Source
		2020	2025	2030	
(1)	Climate Benefits	$2.8	$10	$20	Table ES-9
(2)	Air Quality Health Co-Benefits	$0.7 to $1.8	$7.4 to $18	$14 to $34	Table ES-9
(3)	**Total Benefits**	$3.5 to $4.6	$17.4 to 28	$34 to $54	(1) + (2)
(3a)	With SPC=1.2, assuming non-climate benefits augment capital	$3.6 to $5.0	$17.4 to $31.6	$36.8 to $60.8	(1)+(2)*SPC
(4)	**Compliance Costs**	$2.5	$1.0	$8.4	Table ES-9
(4a)	With SPC=1.2, assuming costs displace capital	$3.0	$1.2	$10.1	(4)*SPC
	Net Benefits				
(5)	*assuming all costs and benefits affect consumption*	$1.0 to $2.1	$16.4 to $27.0	$26 to $46	(3)-(4)
(6)	*assuming costs displace capital*	$0.5 to $1.6	$16.2 to $26.8	$24 to $44	(3)-(4a)
(7)	*Assuming non-climate benefits augment capital*	$1.1 to $2.5	$17.9 to $30.6	$28.4 to $52.4	(3a)-(4)

Notes: We do not apply the SPC to climate benefits to convert to consumption equivalent values because those climate benefits are already in consumption-equivalent terms. Some values differ slightly from those in the original RIA due to rounding. EPA Clean Power Plan RIA available at **https://www3.epa.gov/ttnecas1/docs/ria/utilities_ria_final-clean-power-plan-existing-units_2015-08.pdf**

Figure 1. Original CPP RIA Table

Table ES-9. Monetized Benefits, Compliance Costs, and Net Benefits Under the Rate-based Illustrative Plan Approach (billions of 2011$) [a]

	Rate-Based Approach					
	2020		2025		2030	
Climate Benefits [b]						
5% discount rate	$0.80		$3.1		$6.4	
3% discount rate	$2.8		$10		$20	
2.5% discount rate	$4.1		$15		$29	
95th percentile at 3% discount rate	$8.2		$31		$61	
	Air Quality Co-benefits Discount Rate					
	3%	7%	3%	7%	3%	7%
Air Quality Health Co-benefits [c]	$0.70 to $1.8	$0.64 to $1.7	$7.4 to $18	$6.7 to $16	$14 to $34	$13 to $31
Compliance Costs [d]	$2.5		$1.0		$8.4	
Net Benefits [e]	$1.0 to $2.1	$1.0 to $2.0	$17 to $27	$16 to $25	$26 to $45	$25 to $43

References

Li, Qingran, and William A. Pizer. 2021. “Use of the Consumption Discount Rate for Public Policy over the Distant Future.” Journal of Environmental Economics and Management 107 (May): 102428. **https://doi.org/10.1016/j.jeem.2021.102428**.

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Appendix - Common Approaches for Accounting for Capital Displacement Are Simplistic and Often Wrong

This appendix formally describes the mathematical logic underlying Circular A-4's approach of incorporating capital displacement concerns by simply costs and benefits at a rate of 7 percent and illustrates why that approach fails to accurately reflect the fundamental concern except in very limited situations.

While Circular A-4 notes that the SPC approach is the analytically preferred one, for purposes of simplicity A-4 nonetheless recommends analysts use the two rates for sensitivity analysis—a consumption rate (estimated historically at 3 percent) and an investment rate (estimated historically at 7 percent), notionally as a bound on how capital displacement might affect CBA. The use of the consumption rate is appropriate when all costs fall on consumption and no costs displace capital. However, the 7 percent investment rate is only an appropriate opposing bound under very specific assumptions. For example, if the displaced capital is permanent and the returns are a perpetuity, and benefits themselves are a perpetuity (or more generally, if the pattern of benefits and investment returns are the same). Importantly, the matching of the pattern is a necessary condition to the validity of using the investment rate, implying that the use of the investment rate to reflect capital displacement is only appropriate in very limited circumstances.

To see why, let us walk through this special case for using the investment rate as a substitute for using the analytically correct SPC approach. In the case of permanent capital displacement, each dollar of immediate costs leads to a permanent one-dollar loss in capital. This has no immediate impact on consumers, but that dollar of capital would have returned the investment rate, denoted r_i, to consumers every year in perpetuity. Therefore, a dollar of permanently displaced capital implies consumers face a cost equal to r_i in every year into the future. The present value of this stream of consumer costs is equal to

$$PV(Consumer\ Costs) = \frac{r_i}{1+r_c} + \frac{r_i}{(1+r_c)^2} + \frac{r_i}{(1+r_c)^3} + \cdots = \frac{r_i}{r_c}$$

where the final equality, r_i/r_c, derives from the equation for the present value of a perpetuity. Thus, a dollar of permanently displaced capital is equivalent to r_i/r_c dollars of lost consumption today. For $r_i = 7\%$ and $r_c = 3\%$, this SPC ratio would be 7%/3% = 2.33.

This SPC can easily be used to calculate net benefits within this extreme scenario. For benefits, now assume this regulation generates $\$B$ of consumer benefits annually for each $1 of permanently displaced capital costs. Then under the SPC approach, the net present value is given by

$$PV(Net\ Benefits_{SPC}) = PV(Consumer\ Benefits) - PV(Consumer\ Costs) = \frac{\$B}{r_c} - \$1\frac{r_i}{r_c} \qquad (1)$$

Using the shadow price of capital, this project passes a benefit-cost test if this expression is greater than zero, or $\$B > r_i$.

The alternative approach to the SPC that is commonly used by government analysts, per the recommendation of Circular A-4, is to instead discount both the flow of benefits ($\$B$) and immediate costs ($1) at the investment rate, r_i. While there is no conceptual reason why one should change the benefit calculation to reflect the nature of costs, the intuition given for this alternative approach is that the benefits from a project or policy should deliver the same return or greater than if the costs were instead invested. In this simple extreme case of permanent capital displacement, this approach reaches the same directional conclusion regarding whether a particular project passes the benefit-cost test as under the SPC approach in equation (1). While this intuitive reasoning yields an equivalent result as the analytically correct SPC approach in this

particular case, more generally it does not. And especially for longer-term issues, the use of an investment rate results in very wrong conclusions. To see why the two approaches align in the simple case under consideration, note that the net benefits under this approach would be the perpetuity value of the benefit flows, $\$B$, discounted to the present at the investment rate r_i, minus the immediate \$1 of costs[1]:

$$PV\left(Net\ Benefits_{r_i}\right) = \frac{\$B}{r_i} - \$1 \qquad (2)$$

Comparing the expressions for net benefits under the two approaches—equation (1) for the SPC and (2) when using the investment rate—they both reach the same directional conclusion that the project passes a benefit-cost test if, and only if, $\$B > r_i$. This is the implicit logic underlying Circular A-4's recommendation to discount all costs and benefits at the investment rate—that is, it can mimic the considerations of the shadow price of capital, under certain conditions like when costs permanently displace capital and benefits are paid out as a perpetuity.

However, the symmetry between the two approaches is not a general result, and it in fact breaks down for more general applications where the time pattern of benefits and investment returns differ.

For example, suppose the benefits of this \$1 investment do not pay out as a perpetuity, but rather as a fixed payment of $B = \$10$ received at $T = 40$ years. For this example, we will use $r_c = 3\%$ and $r_i = 7\%$ as our consumption and investment rates, respectively. Therefore, the present value of those benefits would be $\$10/1.03^{40} = \$3.07$. As previously shown, using the shadow price of capital approach, the \$1 in immediate, investment-displacing cost is valued at $\$1 \cdot r_i/r_c = 7\%/3\% = \$2.33$. Hence, this investment yields positive nets benefits of \$0.73 (\$3.07 in benefits less \$2.33 in costs). Had we ignored the SPC approach and instead discounted both benefits and costs at the capital return rate of 7% as is common practice, we would have computed a present value of benefits of only $\$10/1.07^{40} = \$0.67$, yielding an incorrect conclusion of negative net benefits of -\$0.33 (\$0.67 in benefits less \$1 in costs).

If one were to want to solve for the single discount rate that yields the analytically correct conclusion—net benefits of \$0.73—the resulting rate would be about 4.5%[2], which is closer to the 3% consumption rate than is it to the 7% investment rate, highlighting the inappropriateness of using the 7% rate. For longer time horizons, such as those relevant to climate change, the difference between the two approaches grows strongly. Redoing the above example with $B = \$100$ and $T = 100$ years, the resulting rate at which to discount both costs and benefits is 3.3%.

This demonstrates another important point: the SPC approach is in fact a simpler way to account for capital displacement than is the use of a higher discount rate. Namely, if one wishes to account for investment displacement by applying a higher discount rate (that is, above the consumption rate) to both costs and benefits, then one must first determine the appropriate rate. As we have shown, the appropriate rate in this circumstance is much lower than the investment rate, and both depend on the magnitude and time pattern of both benefits and costs, even in the above very simple example. Further, determining this rate would require conducting a full SPC analysis anyway. Hence, the more straightforward and correct approach would be to simply conduct the SPC analysis.

[1] Since the \$1 of costs are assumed to accrue immediately, they need not be discounted.

[2] Discounting both costs and benefits at 4.5% (or more specifically, 4.48%) yields a present value of benefits of $\$10/1.0448^{40} = \$1.73$. The \$1 in costs is accrued in period 0 so is not discounted. Hence, this yields \$0.73 in net benefits, as in the SPC approach.