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Should the government increase investment in infrastructure improvements when interest rates decline?

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Abstract

During recessions, the real interest rate declines and therefore a number of public investment projects might meet the net present value criteria. It has been argued that the government should increase public investment during these times. This paper begins with the assumption that the projects that the government would undertake in these situations are likely to be infrastructure improvement projects. This paper then uses the option theory of investment to determine the criteria for investment. In particular, the government solves an optimal stopping problem. The paper shows that if the government uses the real interest rate to discount the future, the effect of falling real interest rates on investment thresholds is ambiguous. It is therefore not obvious that the government should increase public investment when the real interest rate declines.

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1 Introduction

In the midst of a recession, there are often calls for increased government spending. Some arguments are based on the idea that increased government spending stimulates economic activity thereby reducing the severity of the recession. Other arguments emphasize the role of low interest rates. In particular, the argument is that when the economy is in a recession and real interest rates are low, this represents an opportune time to invest. For example, Krugman (2014) argues:

> There's an obvious policy response to this situation: public investment. We have huge infrastructure needs, especially in water and transportation, and the federal government can borrow incredibly cheaply – in fact, interest rates on inflation-protected bonds have been negative much of the time (they're currently just 0.4 percent). So borrowing to build roads, repair sewers and more seems like a no-brainer.

Such arguments are based on a net present value approach to investing. The basic argument is that government infrastructure projects and other forms of public investment should be financed whenever the net present value is positive. Andolfatto (2011) explains:

> There is a better way of evaluating the net benefit of a government stimulus program. This involves estimating the expected net present value of the program (easier said than done, of course). With the real return on U.S. Treasuries so low (see my previous post), with U.S. infrastructure reportedly in a sorry state, and with so many unemployed construction workers, I would be surprised to learn that there are few positive NPV infrastructure projects currently available.

These quotations are pertinent since the net present value approach is what the government relies on to assess potential infrastructure improvement projects (U.S. Department of Transportation, 2012). Yet, in the private investment literature, many have argued that the net present value approach is an insufficient guide for investment.[1]

The purpose of this paper is to present a model in which the government has to decide when to invest in infrastructure improvements. The model assumes that the government provides some type of infrastructure that produces social utility. Over time, the quality of the infrastructure depreciates, but there is uncertainty about the degree to which it depreciates during any given time interval. For example, changes in the weather or traffic over a particular time interval might influence the degree to which infrastructure depreciates. Given these circumstances, the government faces what is known in the investment literature as an optimal stopping problem.[2] In other words, the government has to decide how long to let the infrastructure depreciate before undertaking an investment to improve the infrastructure.

As shown in the model, an increase in the interest rate has an ambiguous effect on the optimal stopping time.[3] It is therefore not obvious that lower real interest rates should imply that the government invest more in infrastructure improvement projects. Implications for infrastructure investment and discounting are then discussed.

[1] See Dixit and Pindyck (1995).

[2] Optimal stopping problems for investment are part of a literature known as the real option theory of investment. For early work on the real option theory, see Bernanke (1983), McDonald and Siegel (1986), and Abel et al. (1996). For a textbook treatment, see Dixit and Pindyck (1994) and Stokey (2009).

[3] A number of papers in the real option theory have found a positive relationship between interest rates and investment – contrary to the predictions of the net present value approach. See, for example, Williams (1991), Ingersoll and Ross (1992), and Capozza and Li (2002). The possibility is also discussed by Dixit and Pindyck (1994). Capozza and Li (2001) find empirical evidence of a positive relationship between interest rates and residential investment.

2 The Model

Time is continuous and continues forever. There is a government with the sole purpose of determining when to invest in infrastructure improvements in the economy. Suppose that there is a particular quality of infrastructure in the economy at time t denoted $I(t)$. In addition, suppose that society generates welfare from the quality of the infrastructure in the economy, denoted $U[I(t)]$. In addition, suppose that the quality of infrastructure follows a geometric Brownian motion:

$$\frac{dI}{I} = \mu dt + \sigma dz \tag{1}$$

where dz is an increment of a Wiener process and μ and σ are parameters. In what follows, it is assumed that $\mu < 0$ and $\sigma > 0$. These assumptions imply, respectively, that the quality of infrastructure in the economy is decreasing over time and that there is uncertainty about the extent to which the quality of infrastructure is declining in any given interval of time.

Given that the quality of infrastructure is declining over time, the government faces an optimal stopping problem. The government has to decide at what point in time they want to invest in infrastructure improvement. Given the assumption of uncertainty regarding the quality of infrastructure ($\sigma > 0$), it is not possible to solve for the time period in which this change will occur. However, one can identify the level of infrastructure, I^*, at which the government will choose to exercise its option to improve the infrastructure.

Assume that when the government undertakes the investment in infrastructure, the quality of public infrastructure rises to S with corresponding social utility, $U(S)$.[4] The investment involves a borrowing cost rC, where r is the real interest rate and C is the cost of the project. Thus, when undertaking the investment, the benefit is $U(S) - rC > 0$.

The Bellman equation for the government is given as

$$rV(I) = U(I) + \frac{1}{dt}dV \tag{2}$$

where E denotes the expectation. Using Ito's Lemma and equation (1), this can be re-written as

$$\frac{1}{2}\sigma^2 V^2 V''(I) + \mu V V'(I) - rV(I) + U(I) = 0 \tag{3}$$

Note that this is a second-order differential equation in V. Recall that ordinary differential equations have a solution that can be written as

$$V(I) = V_p(I) + a_1 I^{\beta_1} + a_2 I^{\beta_2} \tag{4}$$

where V_p is a particular solution and $a_i I^{\beta_i}, i = 1,2$ are homogeneous solutions. The economic context of this equation can be understood as follows. The particular solution V_p can be thought of as the value of the current infrastructure if there is never any investment to improve quality. The homogeneous solutions can be thought of as the value of the option to undertake the investment project in the future.

The solution to the differential equation is subject to the following conditions. First, it should be true that

$$\lim_{I\to\infty}[V(I) - V_p(I)] = 0 \tag{5}$$

This condition states that as the quality of the infrastructure gets larger and larger, the value of the option to improve public infrastructure should go to zero.

Second, at the point at which the option is exercised, it must be true that the government is indifferent about investing:

$$V(I^*) = U(S) - rC \tag{6}$$

[4] For simplicity, it is assumed that S is simply some known constant.

It follows from equations (5) and (6) that value function satisfies

$$V(I) = V_p(I) + \left[\frac{I}{I^*}\right]^{\beta_1} [U(S) - rC - V_p(I^*)] \tag{7}$$

where $\beta_1 < 0$.

Third, it must be true that the government is optimizing:

$$V'(I^*) = 0 \tag{8}$$

It follows from (7) and (8) that the quality of infrastructure associated with the optimal stopping time satisfies

$$-\beta_1 I^* [U(S) - rC - V_p(I^*)] - V_p'(I^*) = 0 \tag{9}$$

This optimal stopping time condition is important because it represents the precise point at which the government should invest to restore the infrastructure to the quality, S.

It is important to consider the effects of the interest rate on the optimal stopping time. If a reduction in the interest rate causes I^* to increase, then this would imply that a decline in the interest rate would make the optimal stopping time sooner. If this is the case, then low interest rates would make it more likely that some projects would reach the optimal stopping time threshold during the period of low interest rates. On the other hand, if reductions in the real interest rate imply that I^* declines, then the government should actually wait longer before exercising the option to invest.

In order to consider the implications of falling interest rates for the optimal stopping time decision, it is assumed that $U(I) = I^\theta$. Given that $V_p(I)$ is the value of the quality of infrastructure I if no control is ever exercised (i.e. no investment ever takes place), this functional form implies that

$$V_p(I) = \int_0^\infty e^{-rt} U[I(t)]dt = \frac{I^\theta}{r - \mu\theta - (1/2)\theta(\theta - 1)\sigma^2}$$

So that it is possible to get an analytical solution for I^* from equation (9), let $\theta = 1$.[5] It follows from (9) that

$$I^* = \left\{ (r - \mu - (1/2)\sigma^2)[S - rC] + \frac{1}{\beta_1} \right\}^{\frac{1}{2}} \tag{10}$$

where I^* is the optimal stopping threshold.

Given the optimal infrastructure threshold, it is possible to consider how changes in the real interest rate affect this threshold. Note that β_1 is a function of the real interest rate. In particular,

$$\beta_1 = f(r) = \frac{-[\mu - (1/2)\sigma^2] - \sqrt{[\mu - (1/2)\sigma^2]^2 - 2\sigma^2 r}}{\sigma^2}$$

It is straightforward to see that $f'(r) > 0$. Re-writing the optimal stopping threshold yields

$$I^* = \left\{ (r - \mu - (1/2)\sigma^2)[S - rC] + \frac{1}{f(r)} \right\}^{\frac{1}{2}}$$

Thus, the change in the threshold from a change in the real interest rate is given as

$$\frac{\partial I^*}{\partial r} = \frac{1}{2}\left[S - 2rC - \frac{f'(r)}{[f(r)]^2}\right] \left\{ (r - \mu - (1/2)\sigma^2)[S - rC] + \frac{1}{f(r)} \right\}^{-\frac{1}{2}} \lesseqqgtr 0 \tag{11}$$

The sign of this expression will be determined by the sign of the first term in brackets. Without calibrating the parameters of the model the effect of the real interest rate on the optimal stopping threshold is ambiguous.

[5]The assumption of linear utility implies that the marginal utility of infrastructure is constant. It can be shown that the result would hold even in cases in which the marginal utility is increasing in the quality of infrastructure, i.e. $\theta > 1$.

3 Implications

There are three important implications to draw from this analysis. First, while the arguments based on the net present value approach described in the introduction imply the government should increase infrastructure investment when real interest rates decline, the model provides an ambiguous result. The reason for ambiguity is that there are two effects of the interest rate on the investment decision. The first effect is that lower interest rates reduce borrowing costs thereby increasing the net benefit of the project. The second effect is that the reduction in the interest rate causes the government to put more weight on the future. This increases the value of the option to wait.

The second important implication is as follows. Those who advocate the net present value approach would have the government undertake any investment for which the net present value is positive. Indeed, as advocates of this approach argue, it is likely that many (if not most) projects that the government would like to undertake would satisfy this condition when the real interest rate is near zero. However, when one views the government's choice as an optimal stopping problem, it is only optimal for the government to invest in infrastructure improvement when $I \leq I^*$. In other words, it is only optimal to increase infrastructure investment if the decline in real interest rates pushes I into its optimal stopping region.

A third important implication to draw from the government's optimal stopping problem is regarding how the government discounts the future. It was assumed (as it is conventionally assumed in the option literature) that the investor, in this case the government, uses the risk-free real rate of interest as its discount rate. If, for example, the government used a different rate to discount the future, such as assuming a constant, pure rate of time preference, then the optimal stopping threshold would be

$$I^* = \left\{ (\rho - \mu - (1/2)\sigma^2)[S - rC] + \frac{1}{\beta_1} \right\}^{\frac{1}{2}}$$

where ρ is the pure rate of time preference. In addition, this would imply that β_1 is no longer a function of the real rate of interest. It is therefore easy to see with these assumptions that a reduction in the real interest rate would increase the optimal stopping threshold. This implies that during time periods in which real interest rates decline, it is likely that some investment projects will reach their optimal stopping region before they would have otherwise. In this case, public investment can and should increase. However, as noted above, the degree to which public investment increases is likely to be lower than under the net present value criteria since the government should only invest if $I \leq I^*$.

There is therefore an important question regarding the discount rate that the government should use when evaluating investment projects. What matters for the government when choosing a discount rate is an understanding of what causes the fluctuations in the real interest rate. For example, in a standard consumption model, the real interest rate is a function of the rate of time preference and the expected growth rate of the economy (Selgin, et al. 2015). It is also possible that real interest rates fluctuate as a result of a flight to safety or liquidity (Andolfatto, 2012).

The government might want to value the future in a way that is consistent with the preferences of the individuals in the economy. This would imply using the pure rate of time preference to discount the future. If changes in the pure rate of time preference explain changes in the real interest rate over time, then the real rate of interest would be a useful market indicator for the discount rate that the government should employ. However, if changes in the real interest rate are caused by other factors, the government might wish to employ a constant pure rate of time preference as its discount rate.

Appendix: A Note on Multiplier Effects

As alluded to in the introduction, the purpose of this paper is to determine whether the government should increase infrastructure investment when the real interest rate falls. In fact, the quotes in the introduction of the paper suggest that government infrastructure investment is worthwhile *even in the absence of a multiplier effect.* As a result, in the main part of the text, the multiplier effect is not mentioned. In this appendix, three reasons are provided for excluding the discussion of a multiplier effect in the main part of the text.

First, the arguments put forth by Krugman and Andolfatto in the introduction are representative of the views of most economists regarding infrastructure investment. These arguments are based on a positive net present value criteria for public investment used in public finance textbooks, such as Hyman (2013) and Rosen and Gayer (2013). In addition, as alluded to in the main text, this is also the criteria of the U.S. Department of Transportation. The main purpose of the paper is to challenge the use of the positive net present value criteria as a way of evaluating infrastructure improvement projects.

Second, the focus of the paper is on the effect of changes in the real interest rate on optimal stopping times. In the paper, the value of the infrastructure improvement is taken as given. In other words, the value of the infrastructure improvement is consistent with any value of the multiplier because this value is assumed to be exogenous. As it pertains to the paper, the only way in which the multiplier matters for the analysis presented in this paper is if the multiplier is a function of the real interest rate. If the multiplier takes on the same value independent of the real interest rate, then the results presented in the paper remain unchanged and the discussion of the multiplier is a moot point.

Third, suppose that the real interest rate does have an effect on the multiplier and therefore the value of the project is a function of the real interest rate, $S = S(r)$. It is straightforward to show that the effect of a change in the real interest rate on the optimal stopping time remains ambiguous:

$$\frac{\partial I^*}{\partial r} = \frac{1}{2}\left[S(r) + rS'(r) - 2rC - \frac{f'(r)}{[f(r)]^2}\right]\left\{(r - \mu - (1/2)\sigma^2)[S(r) - rC] + \frac{1}{f(r)}\right\}^{-\frac{1}{2}} \lesseqqgtr 0$$

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