Rule-Based Resource Revenue Stabilization Funds: A Welfare Comparison

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ABSTRACT

Resource prices, and petroleum prices in particular, are volatile and difficult to predict, so government revenue in resource-producing regions is also uncertain and volatile. Adjusting government expenditure in response to these revenue movements involves economic, social and political costs. Many jurisdictions have established rule-based revenue stabilization funds to address revenue volatility, but there is little evidence on whether these funds improve welfare or if some fund designs increase welfare more than others. Using Monte Carlo techniques, we provide a quantitative welfare comparison of several types of rule-based stabilization funds for a petroleum-producing jurisdiction. We find large potential gains from the use of a fund to stabilize revenue, but some fund types reduce welfare, particularly those that accumulate large stocks of assets or debt. A fund that performs well, and is generally robust to changes in the simulation parameters, has a fixed deposit rate out of resource revenue and a fixed withdrawal rate out of assets.

Keywords: Petroleum prices, Resource revenue volatility, Fiscal rules, Stabilization funds, Savings funds

1. INTRODUCTION

Non-renewable natural resources generate more than 25 percent of government revenue in 50 countries and provide an even higher share of revenue in petroleum-producing jurisdictions (IMF, 2007).[1] Resource prices are volatile and difficult to predict, so government revenue in resource-producing regions is also uncertain and volatile. Adjusting government expenditure in response to revenue movements involves economic, social and political costs.[2] For example, increased government expenditure volatility can increase private sector uncertainty and, thereby, reduce investment, growth and welfare. Volatility in government revenue that leads to volatile movements in government spending and stop-go pro-cyclical fiscal policies can accentuate economic cycles (Boothe, 1995; Sturm, Gurtner, and Alegre, 2009; Villafuerte and Lopez-Murphy, 2010; Erbil, 2011;

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1. Several US states (Alaska, North Dakota, Wyoming, Montana, New Mexico, Oklahoma, Louisiana) and Canadian provinces (Alberta, Saskatchewan, and Newfoundland) are also heavily reliant on non-renewable energy-related resource revenue.

2. These costs are discussed in more detail in Landon and Smith (2010).

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Ploeg and Venables, 2012).[3] The rapid expansion of programs and capital spending during revenue booms can raise input prices and stretch the capacity of governments to provide services and monitor spending, leading to waste, inefficiency and the unproductive use of government funds (Barnett and Ossowski, 2002). Similarly, during a revenue collapse, it is often difficult to first cut spending on government programs with the lowest benefit. Further, a reduction in capital spending caused by a decline in resource revenue may mean abandoning viable projects that are crucial to a country's development. To the extent that it is easier politically to raise government spending in booms than to reduce spending in recessions, revenue volatility may also lead to the expansion of government and the implementation of an unsustainable fiscal plan.[4]

The optimal response to an uncertain revenue stream is an expenditure path that maximizes the expected present value of intertemporal welfare given the expected path of revenue (Bremer and Ploeg, 2013; Ploeg and Venables, 2011). The solution to this type of problem is complex to calculate and difficult to explain to the public and government decision makers, so "implementing solutions is cumbersome and the results are not as transparent as the political process requires" (Engel and Valdés, 2000, 14). As a feasible alternative, numerous jurisdictions have created resource revenue stabilization funds.[5] Using some form of *ad hoc* rule, a revenue stabilization fund channels a portion of resource revenue into a fund when resource prices are high, and withdraws assets from the fund to maintain spending when prices are low. By weakening the link between current resource revenue and current budgetary revenue, a stabilization fund can smooth expenditure.[6]

Rule-based stabilization funds have several desirable features. Bacon and Tordo (2006) argue that formal rules for payments into and out of a fund facilitate public scrutiny and inform the debate on fiscal choices, while Kumar, Baldacci, and Schaechter (2009) note that rules that are transparent and backed by appropriate fiscal institutions promote better fiscal performance. Further, a fund can be designed so that policy makers do not require forecasts of future resource prices, which is beneficial since these prices are highly uncertain. In addition, stabilization funds can reduce revenue uncertainty since current and future budget revenues depend on known past contributions to the fund. For jurisdictions that rely heavily on resource revenue, a policy that stabilizes government spending would be expected to also stabilize the overall economy. Finally, by providing a smoother revenue stream to government, a stabilization fund may prevent cyclical tax rate changes. Barro (1979) argues that this may reduce the incentive to concentrate market activity in periods with temporarily low tax rates, thereby, improving economic efficiency.

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3. Lane (2003) shows that OECD countries with more volatile output run more pro-cyclical fiscal policies. Accentuating economic cycles may be costly. For example, countries with highly variable terms of trade are observed to have slower growth rates, possibly due to the costs of shifting resources between expanding and contracting sectors (Ramey and Ramey, 1995; Blattman, Hwang and Williamson, 2007; Ploeg and Poelhekke, 2009).

4. Frankel (2011) finds it is common for governments to unrealistically extrapolate booms into the future. Similar evidence is provided in Boothe (1995) and Kneebone and McKenzie (2000).

5. Descriptions and a discussion of the stabilization funds used in a variety of countries can be found in Fasano (2000), Davis, Ossowski, Daniel and Barnett (2003) and Ossowski, Villafuerte, Medas and Thomas (2008).

6. An alternative method of addressing a volatile income stream is to hedge using futures or options markets (Daniel, 2001; Swidler, Buttimer and Shaw, 1999). Despite the apparent attractiveness of this approach, hedging cannot remove all volatility and is often costly, particularly for longer horizons. Also, the public may view hedging as "speculation," so it may entail significant political risk (Daniel, 2001; Caballero and Cowan, 2007; Frankel, 2010). As a result, few commodity exporting jurisdictions hedge (Blas, 2009; Borensztein, Jeanne and Sandri, 2009). Another method of smoothing revenue is to diversify the economy (and, thereby, the tax base) away from resource-related activities. This may, however, be inefficient since it can run counter to a jurisdiction's comparative advantage. For more on these alternatives, see Landon and Smith (2010).

Many jurisdictions utilize revenue stabilization funds, but there is little empirical research on whether stabilization funds improve welfare or on how stabilization fund characteristics affect fund performance.[7] While Wagner and Elder (2005) and Sobel and Holcome (1996) find that a fund can increase fiscal stabilization, they do not address the question of whether alternative fund structures could yield greater stabilization, nor do they quantify the welfare impact of a fund. Arrau and Claessens (1992), Engel and Valdés (2000) and Bartsch (2006) employ Monte Carlo simulations to determine optimal government saving in the presence of commodity price shocks, but do not make welfare comparisons across rule-based funds. The study by Borensztein, Jeanne and Sandri (2009) uses a numerical approach to assess welfare gains in commodity exporting regions, but their focus is on optimal hedging strategies, not stabilization funds. Pieschacón (2012) shows that fiscal discipline can smooth consumption and increase welfare following oil price shocks, but does not evaluate or compare stabilization rules. Ploeg, Stefanski and Wills (2011) consider rules along a spectrum from a permanent income rule to a "spend-all" rule and find that, for Ghana, expenditure should be brought forward somewhat to stimulate development. Maliszewski (2009) employs numerical simulations to examine the impact on a petroleum-producer's welfare of employing various fiscal rules and concludes that *ad hoc* rules perform poorly. In contrast, using simulations and parameter values that match the Chilean economy, Engel, Neilson and Valdés (2011) find considerable benefit from the use of a simple rule.

We contribute to the literature by quantifying the impact on welfare of different types of rule-based resource revenue stabilization funds. This allows us to determine whether these funds improve welfare and whether some fund designs increase welfare more than others. Our results also help identify fund characteristics that may cause funds to be significantly altered or abandoned.[8] In previous work (Landon and Smith, 2013), we calculate the relative welfare performance of stabilization funds using historical data for the Canadian province of Alberta. In contrast to this earlier analysis, the current study explicitly incorporates revenue uncertainty. We use Monte Carlo techniques to specify a large number of different possible paths for future revenues and compare the *expected* welfare performance of different funds given these paths. This forward-looking approach contrasts with our previous paper which was a time-period and jurisdiction-specific counterfactual simulation.

Although we use the term "stabilization", the funds we examine are both *stabilization* and *savings* funds. Since resource revenue arises from the conversion of a physical asset into a financial asset, proponents of *savings* funds suggest that governments treat this revenue as wealth and, therefore, spend only the annuity value of resource wealth, leaving the balance in a savings fund to support the provision of services to future generations.[9] The welfare measure used in the current study takes a standard intertemporal form that includes an infinite horizon and volatility aversion. As a result, this welfare measure incorporates the objective of a stabilization fund—the reduction

7. A small related literature examines optimal lifetime consumption and savings "rules-of-thumb" from the perspective of an individual. See, for example, Love (2013) and Winter, Schlafmann and Rodepeter (2012).

8. Examples of jurisdictions that have significantly altered or abolished resource revenue stabilization or savings funds include Oman, Papua New Guinea, Mexico, Venezuela, Gabon, Chad, Ecuador, Nigeria, the US state of Alaska and the Canadian province of Alberta.

9. Hartwick (1977), Engel and Valdés (2000), Barnett and Ossowski (2002), and Davis, Ossowski, Daniel and Barnett (2003) discuss savings funds and the related issues of intergenerational equity and fiscal sustainability. Hartwick (1977) shows that, in a deterministic setting with resource depletion, intergenerational equity can be achieved by transforming a non-renewable resource into capital and consuming the services of this capital, thereby achieving a constant per capita consumption path over time.

of expenditure volatility, but also gives weight to the goal of a savings fund—the accumulation of assets to support future spending. [10]

Our comparison of stabilization funds focuses on a petroleum-producing jurisdiction since, for many countries and subnational governments, petroleum products are a major revenue source. Petroleum prices are also one of the most volatile types of commodity prices, so stabilization is likely to be particularly important to petroleum-producing regions. However, our findings are likely to be applicable to jurisdictions that rely on revenue from other commodities that are characterized by price volatility, such as natural gas.

As the future path of resource-based revenue is uncertain, we use historical petroleum price data to simulate 1000 possible revenue paths and compare the expected intertemporal welfare of each stabilization fund given these paths. Since resource depletion is likely to have an important impact on welfare, we evaluate the stabilization funds under two radically different depletion scenarios. In one, petroleum production continues indefinitely, while in the other production falls rapidly to zero. The non-depletion scenario emphasizes the stabilization function of a fund, while the depletion case focuses the analysis on both the stabilization and savings roles of a fund. Welfare is evaluated over an infinite horizon and the welfare implications of the different funds are quantified relative to the welfare generated by a policy of spending all revenue as it is received. We also compare the welfare of rule-based funds to the welfare of the (unattainable) perfect foresight "permanent income" expenditure path. The benchmark analysis employs the fairly standard assumptions of a coefficient of relative risk aversion of 2 and a discount rate of 3 percent, but we also consider a value of 4 for the risk aversion parameter, and a 2 percent discount rate. The interest rate is treated as exogenous to the domestic country's saving and lending decisions, consistent with the characteristics of many resource-producing countries that are small open economies.

We find large potential gains from the use of a stabilization fund to smooth government expenditure. These gains can be, for example, much greater than the benefit of eliminating the US business cycle as measured by Lucas (2003). The main reason for this is the high volatility of petroleum-based revenue. This is consistent with the findings of Pallage and Robe (2003) that business cycle fluctuations are more costly in developing countries because developing economies are more volatile. Although large, the gains we measure do not include the cost of moving resources between contracting and expanding sectors (Engel and Valdés, 2000; Maliszewski, 2009), or the negative impact of volatility on investment and, thereby, on output growth (Barlevy, 2004; Cavalcanti, Mohaddes and Raissi, 2012), so the overall benefit of a stabilization fund is likely to be greater than that found here.

The second principal finding is that the low durability of some stabilization funds is likely due to instability imbedded in their design. For example, there is a high probability that some funds will amass extremely large stocks of assets or debt. The accumulation of large asset stocks is unlikely to be sustainable from a political perspective, while the accumulation of a large debt may necessitate a level of borrowing that is not feasible. The critical design shortcoming exhibited by these funds is a lack of feedback from the stock of assets in the fund to current expenditure. Examples of funds without feedback are those that fix expenditure at a constant level or that base expenditure only on a moving average of past resource revenue.

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10. *Savings* funds are sometimes referred to as *intergenerational* funds, and *stabilization* funds as *liquidity* or *short-run smoothing* funds. A third type of fund, a *parking* fund, is a fund in which assets are temporality parked when a jurisdiction is unable to absorb all its resource revenues (Ploeg and Venables, 2012).

Third, while there are potentially large welfare benefits from the use of a stabilization fund, some funds yield poor outcomes. In fact, some fund types yield lower welfare than a policy of spending all revenue as it is received. The main reason for poor fund performance is the excessive accumulation of assets. The accumulation of a large stock of assets entails the sacrifice of current for future consumption, which is costly in terms of welfare since a more stable consumption path is preferred. The more successful funds are those that stabilize expenditure while limiting the accumulation of assets and debt. One of the best performing funds from a welfare perspective has a fixed contribution rate out of resource revenue and a fixed withdrawal rate out of accumulated assets. However, even with this type of fund, too large a deposit rate and too small a withdrawal rate can result in the accumulation of a large quantity of assets and, thereby, yield low welfare.

Finally, the best fund type, a fund with fixed deposit and withdrawal rates, is relatively robust to changes with respect to the yield on assets, the discount rate, the proportion of revenue derived from resources, the degree of risk aversion and the pattern of depletion. This suggests that the best type of fund is likely to be applicable to many different jurisdictions. As a result, it is not necessary to design different funds for different situations or alter the design of the fund in response to a change in the environment. This is important as it reduces the need for discretionary changes that can, potentially, increase volatility.

The outline of the paper is as follows. The next section discusses the explicit characteristics of the stabilization funds, while section 3 outlines the methodology used to compare the welfare benefits of the funds. Section 4 gives the results and section 5 provides a discussion of the results and concluding remarks.

2. THE STABILIZATION FUNDS

We consider four major types of rule-based stabilization funds. These funds are based on the most popular types of fund rules that have been adopted by governments around the world.[11] Government expenditure is assumed to be determined by current revenue plus withdrawals (W) from the fund less deposits (D) to the fund. That is, government program spending in period t is:

$$G_t = R_t^O + R_t^{NR} - (D_t - W_t),$$ (1)

where R_t^O is non-resource government revenue in period t excluding the fund's interest earnings, R_t^{NR} is natural resource revenue received in period t, and $(D_t - W_t)$ represents period t deposits to the stabilization fund net of withdrawals. If a fund stabilizes revenue, net of deposits to and withdrawals from the fund, it will stabilize expenditure.

Equation (1) implies that the government does not save or borrow other than to the extent required by the deposit and withdrawal criteria of the fund. As a result, assets in the fund represent total net government assets and accumulate as follows:

$$A_t = (1 + r_t)(A_{t-1} + R_t^O + R_t^{NR} - G_t) = (1 + r_t)(A_{t-1} + D_t - W_t),$$ (2)

where A_t is real assets held at the *end* of period t and r_t is the real interest rate in period t.

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11. An important difference between the funds we consider and funds that have been employed in practice is that we specify a rule for withdrawals, while few actual funds have explicit withdrawal criteria. The specification of withdrawal criteria is necessary to compare funds, but also eliminates the expenditure discretion inherent in most existing funds.

2.1 The *Moving Average* Fund

With a *moving average* fund, all current natural resource revenue is deposited in the fund (a 100 percent deposit rate), while withdrawals are given by an equally-weighted moving average of past resource revenue. This implies government expenditure equal to:

$$G_t = R_t^O + R_t^{NR} - (D_t - W_t) = R_t^O + R_t^{NR} - R_t^{NR} + MA_{nt}^{NR} = R_t^O + MA_{nt}^{NR}, \tag{3}$$

where

$$MA_{nt}^{NR} = \frac{1}{n} \sum_{j=1}^{n} R_{t-j}^{NR}, \tag{4}$$

and n is the length of the moving average in years. The simulations below use values for n of 2, 3, 5, 7 and 10.

A *moving average* fund is expected to smooth government expenditure because the contribution to expenditure of natural resource revenue net of deposits and withdrawals from the fund depends only on the moving average of natural resource revenue, not on current resource revenue. Since the moving average of resource revenue tends to be less volatile than actual resource revenue, expenditure will be less volatile as well. Russia created a fund similar to the *moving average* fund, but with no withdrawals until the fund had accumulated a minimum of 500 billion rubles (Bacon and Tordo, 2006). Algeria employed a *moving average* fund that incorporated a borrowing constraint (Ossowski, Villafuerte, Medas, Thomas, 2008), while Venezuela used a *moving average* fund at one time with a cap on the total assets in the fund (Davis, Ossowski, Daniel, Barnett, 2003).

2.2 The *Revenue Band* Fund

A *revenue band* fund is a variation on the *moving average* fund that is designed to smooth the impact on spending of large movements in revenue only. If current period natural resource revenue is within a fixed percentage, s, of a moving average of past resource revenue, no deposits to the stabilization fund or withdrawals from the fund are made and all resource revenue is spent in the current period. If current natural resource revenue exceeds the moving average of past revenue by more than the percentage s, the difference between the current value of natural resource revenue and $(1 + (s/100))$ times the moving average are deposited in the stabilization fund. Conversely, withdrawals from the fund occur if current revenue falls below $(1 - (s/100))$ of the moving average. Therefore, the *revenue band* fund supports government spending in period t of:

$$G_t = \begin{cases} R_t^O + (1 + (s/100))MA_{nt}^{NR} & \text{if} \quad (1 + (s/100))MA_{nt}^{NR} \leq R_t^{NR} \\ R_t^O + R_t^{NR} & \text{if} \quad (1 - (s/100))MA_{nt}^{NR} \leq R_t^{NR} \leq (1 + (s/100))MA_{nt}^{NR} , \\ R_t^O + (1 - (s/100))MA_{nt}^{NR} & \text{if} \quad R_t^{NR} < (1 - (s/100))MA_{nt}^{NR} \end{cases} \tag{5}$$

where $0 < s/100 < 1$. In the simulations, we set s equal to 5, 10 and 25, implying band widths of 10, 20, and 50 percent of the moving average. As s approaches zero, the width of the band shrinks, net deposits, $D_t - W_t$, approach the value given by the *moving average* fund, and the impact on current spending of movements in current resource revenue goes to zero. This type of fund is similar

to the copper stabilization fund once used by Chile as well as one permutation of the petroleum stabilization fund of Venezuela.[12]

2.3 The *Rainy Day* Fund

The purpose of a *rainy day* fund is to smooth spending by preventing large declines in government expenditure when current revenue falls. If current natural resource revenue exceeds the moving average of past revenue, a fraction $(1-k)$ of resource revenue is deposited in the *rainy day* fund. When resource revenue falls below the moving average of past revenue, it is a "rainy day", and the fund is used to ensure that government spending does not fall below the sum of non-resource revenue and a fraction k of the moving average of past resource revenue.[13] Hence, the *rainy day* fund implies government expenditure:

$$G_t = \begin{cases} R_t^O + kR_t^{NR} & \text{if} \quad MA_{nt}^{NR} \le R_t^{NR} \\ R_t^O + kMA_{nt}^{NR} & \text{if} \quad R_t^{NR} < MA_{nt}^{NR} \end{cases}, \tag{6}$$

where $0 < k < 1$ and savings during a "rainy day" equals $R_t^{NR} - kMA_{nt}^{NR}$, which may be positive or negative. In the simulations, the parameter k takes on values of 0.50, 0.75, 0.85 and 0.95.

Venezuela once used a fund of this type (Ossowski, et al., 2008) and the Canadian province of Alberta had a fund with similar characteristics. Although not generally based on natural resource revenue, 47 US states also maintain some type of "rainy day" fund (Filipowich and McNichol, 2007; Rueben and Rosenberg, 2009).

2.4 The *Fixed Deposit–Fixed Withdrawal* Fund

One of the simplest forms of rule-based funds involves the deposit of a fixed proportion, d, of nonrenewable resource revenue in the fund each year and the withdrawal of a fixed proportion, w, of the assets in the fund at the beginning of each year (before that year's deposit). This type of *fixed deposit–fixed withdrawal* fund yields government expenditure in period t of:

$$G_t = R_t^O + R_t^{NR} - dR_t^{NR} + wA_{t-1} = R_t^O + (1-d)R_t^{NR} + wA_{t-1}, \ 0 < d < 1, \ 0 < w < 1. \tag{7}$$

In the simulations below, we consider deposit rates of 10, 25, 50, 75 and 100 percent, and withdrawal rates of 5, 10, 25 and 50 percent, so 20 different deposit-withdrawal rate combinations are evaluated.

The *Norwegian Government Pension Fund–Global* is an example of a *fixed deposit–fixed withdrawal* fund. One hundred percent of petroleum revenue is deposited in the fund and the goal of the fund is to allocate real interest earnings to the budget each year, with the long term interest rate assumed to be 4 percent (Jafarov and Leigh, 2007).[14] Other examples of jurisdictions with fixed

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12. These funds utilize a band around a reference commodity price (Arrau and Claessens, 1992; Fasano, 2000). The reference price employed by Chile, although set by a panel of experts, could be closely proxied by a 10-year moving average of past prices (Davis, Ossowski, Daniel and Barnett, 2003) and, thus, is consistent with the *revenue band* specification used here.

13. It is convenient, for expositional purposes, to link directly the savings rate $(1-k)$ and the lower bound on spending (a fraction k of the moving average of past revenue). Without this link, the savings rate could, for example, be 5 percent of current revenue and the lower bound could depend on 90 (rather than 95) percent of the moving average of past revenue. Relaxing the direct link between the savings rate and the lower bound on expenditure does not change any conclusions.

14. The Norwegian approach is an example of a "bird-in-hand" rule (which precludes borrowing), where the withdrawal rate is constant and equal to the long term interest rate and all non-renewable resource revenue is deposited in a fund

deposit funds are Alaska, which has a fund that has had deposit rates of 25 and 50 percent, and the Canadian province of Alberta, which employed a fund with a 30 percent and then a 15 percent deposit rate before regular deposits were discontinued (Davis, Ossowski, Daniel and Barnett, 2003).

3. METHODOLOGY

3.1 Overview

The methodology used to compare the welfare of the stabilization funds involves several steps. First, to incorporate the uncertainty of the future path of resource revenue, 1000 potential government revenue paths are simulated. Each revenue path is used to generate a path for government spending under each permutation of each type of stabilization fund.[15] The expenditure paths for each permutation of each stabilization fund are used to calculate the expected utility for that fund. These expected utility values are then employed to calculate the welfare of each stabilization fund relative to the welfare of the baseline, where the baseline path is one in which all revenue is consumed as it is received, so baseline expenditure is $G_t = R_t^O + R_t^{NR}$. This baseline case is applicable to many countries, particularly poorer developing countries, which are often under pressure to use all resources to finance current government programs.[16] As the baseline involves no stabilization, it is a useful benchmark against which to compare the performance of the stabilization funds because it generates a level of welfare that any viable stabilization fund should meet or exceed.

3.2 Calculation of the Welfare Benefits

We compare stabilization funds using an explicit intertemporal welfare measure that depends positively on the present and future provision of government-provided goods and services, and negatively on government expenditure volatility. This is important because funds involve, to varying degrees, an inherent trade-off—a stabilization fund can reduce the volatility of expenditure, which will increase welfare, but the process of accumulating assets in the fund lowers the current provision of government services, which is a cost to the current users of those services. For example, a simple way to greatly reduce expenditure volatility in petroleum producing jurisdictions would be to deposit all non-renewable resource revenue in a fund and base current expenditure entirely on much more stable non-resource revenue. While this type of fund would stabilize expenditure, it would do so by greatly reducing the level of current expenditure.

The welfare gain attributable to a stabilization fund is measured as the proportion of government expenditure, the "tax," that the representative individual would be willing to give up

(Maliszewski, 2009; Ploeg and Venables, 2012). Some funds (the Alberta Heritage Savings Trust Fund, for example) withdraw real annual investment earnings, rather than a fixed percentage of assets. The volatility of annual returns makes these withdrawals more variable than those associated with a fixed withdrawal rate or withdrawals based on a long run average of real earnings.

15. The analysis is partial equilibrium in the sense that we do not allow the different paths of government spending under the various rule-based funds to affect prices, interest rates, or growth in the economy, changes which, in turn, could have implications for the paths of revenue and expenditure. Further, since we focus on how fiscal rules stabilize government expenditure, we do not consider how private individuals might respond to oil price uncertainty, nor how private individuals' consumption and saving might respond to different government fiscal rules and how this could affect the welfare gains from different fiscal rules.

16. Winter, Schlafmann and Rodepeter (2012) use a policy identical to this baseline as one rule-of-thumb in their analysis of individual consumption behavior.

in every period to be guaranteed the stabilization fund expenditure path rather than the baseline path in which all revenue is spent as it is received.[17] More formally, the welfare gain from a stabilization fund is the value of τ that makes expected utility under the baseline equal to expected utility under the stabilization fund, so τ, as a percent of government expenditure, is the solution to:

$$\sum_{j=1}^{1000} \Pr_j \left[\sum_{t=0}^{\infty} \frac{U(G_{tj}^{BL})}{(1+\rho)^t} \right] = \sum_{j=1}^{1000} \Pr_j \left[\sum_{t=0}^{\infty} \frac{U((1-(\tau/100))G_{tj}^{SF})}{(1+\rho)^t} \right], \tag{8}$$

where the superscript *BL* denotes the baseline expenditure path against which each stabilization fund is compared, *SF* denotes the stabilization fund expenditure path, $\Pr_j$ is the probability of resource price path *j*, and ρ is the discount rate.[18] This procedure yields one value of τ for each permutation of each stabilization fund. If the stabilization fund is no better than the baseline policy of spending all revenue as it is received, τ is zero. If τ is negative, welfare is higher under the baseline policy than with the stabilization fund. The larger the value of τ, the greater the relative welfare of the stabilization fund.

The utility function for each period is assumed to have the standard constant relative risk aversion (CRRA) form:

$$U(G_t) = \frac{G_t^{1-\gamma}}{1-\gamma}, \tag{9}$$

where γ is the coefficient of relative risk aversion. As noted by Borensztein, Jeanne, and Sandri (2009), the homotheticity of the CRRA utility function makes the calculation of τ tractable.[19]

Assuming the parameter γ in the CRRA utility function is positive, agents are risk averse, so utility rises with smoother consumption. In addition, agents exhibit "prudence" and, thus, prefer to undertake precautionary saving.[20] The CRRA functional form has been employed in many studies of the welfare impact of business cycles and consumption volatility, such as Barro (2009), Lucas (2003), and Morduch (1995).[21] An alternative to the CRRA utility function is a function with constant absolute risk aversion (CARA). However, experimental evidence is more consistent with decreasing absolute risk aversion (Friend and Blume, 1975), and Merton (1969, 256) argues that constant absolute risk aversion is behaviorally less plausible than constant relative risk aversion. The quadratic utility function is also an unattractive alternative as it exhibits increasing absolute

17. This methodology of quantifying welfare is used in other contexts by, for example, Lucas (2003), Pallage and Robe (2003) and Borensztein, Jeanne, and Sandri (2009).

18. We calculate the probability ($\Pr_j$) of each of the 1000 price paths taking into account that the price paths depend on random errors drawn from a normal distribution.

19. In general consumer theory, it is standard to employ ordinal utility since preference intensities cannot be observed. Our analysis requires the use of cardinal utility comparisons, which is accepted practice in specific contexts, such as decision making under risk, and discounted utilities for intertemporal evaluations (Kobberling, 2006).

20. The benefit of precautionary saving is greater the larger is the index of relative prudence: $-U'''(G)G/U''(G) = 1 + \gamma$; that is, the larger is γ (Kimball, 1990; Carroll and Kimball, 2008; Ploeg, 2010).

21. Other researchers that utilize this type of utility function to examine the welfare consequences of volatility include Barlevy (2004), Bems and Carvalho Filho (2011), Borensztein, Jeanne, and Sandri (2009); Céspedes and Velasco (2011), Durdu, Mendoza, and Teronnes (2009), Engel and Valdés (2000), Ghosh and Ostry (1997), Maliszewski (2009), and Pallage and Robe (2003). The specification in equation (9) assumes utility is separable in private and government-provided goods, so the level of private consumption does not affect the welfare of government-provided goods. There are also no economies of scale associated with government spending and no public good aspects to spending.

risk aversion. For these reasons, and to keep the number of cases examined manageable, we undertake our analysis using the CRRA utility function.[22]

3.3 Modeling the Path of Government Revenue

Government revenue in each period is the sum of non-stochastic non-resource revenue and stochastic resource revenue. Resource revenue is assumed to be raised through a linear resource production tax. Since a stabilization fund is more likely to endure if its welfare performance is robust across different production scenarios, we examine two contrasting resource production paths—a non-depletion scenario and a depletion scenario.[23] In both the non-depletion and depletion scenarios, the quantity of the resource collected by the production tax is known, so the only government revenue uncertainty is with respect to the resource price that determines the value of the production tax.[24]

To model the stochastic nature of resource revenue, we generate 1000 different paths for the resource price. The process determining the resource price is represented by a first order autoregressive process in the natural log of the real US dollar price of petroleum, p. This process is estimated using annual data for 1972 through 2011.[25] The sample period begins in 1972 as Dvir and Rogoff (2009) identify a break point in the behaviour of the petroleum price in 1972. The estimates of the petroleum price regression are:[26]

$$p_t = 0.6861 + 0.8185 p_{t-1} + \hat{\varepsilon}_t ,$$
$$\quad (0.313) \quad (0.089)$$

(10)

where $\hat{\varepsilon}$ is the regression residual, and standard errors are in brackets.[27]

To generate 1000 resource revenue series, a random number generator is used to draw

22. One characteristic of the CRRA utility function is that it links the values of the coefficient of relative risk aversion and the intertemporal elasticity of substitution, in contrast to the Epstein-Zin utility function used by Obstfeld (1994) and Barro (2009). Barro (2009) finds the CRRA and Epstein-Zin functional forms yield different welfare results only if income shocks follow a random walk, which is not the case here as the revenue generating process is found to be stationary. Also, for a CRRA utility function, a value of 2 for γ implies an intertemporal elasticity of substitution of 0.5. Obstfeld (1994, 1484) notes that an elasticity of substitution of 0.5 and a coefficient of relative risk aversion of 2, as used here, are close to the estimates provided by Epstein and Zin.

23. We do not consider a scenario where resource production grows over time. With growing production, it seems likely that the motivation to save for future consumption would decrease, but there would still be short term revenue stabilization benefits from the use of a fund.

24. For most petroleum-producing jurisdictions, the year-to-year volatility of revenue is determined almost entirely by price volatility rather than quantity volatility (Arrau and Claessens, 1992; Spatafora and Samake, 2012). While other variables in the economy, such as the return on fund assets, might also be viewed as uncertain, we focus solely on petroleum price uncertainty due to the large magnitude of petroleum price variations. Also, this is the key form of uncertainty faced exclusively by petroleum producers.

25. The data used to calculate the real oil price are: the US GDP deflator, downloaded from the US Bureau of Economic Analysis on 27 January 2012; and the average world petroleum price in US dollars per barrel ("Commodity prices, Crude oil (petroleum)–world"), downloaded from the IMF's *International Financial Statistics* database on 26 January 2012.

26. The coefficient estimates are similar to other studies that employ this type of regression equation (Bartsch, 2006; Engel and Valdés, 2000) and imply that the real petroleum price is stationary. Pieschacón (2012) argues that the empirical literature generally supports the stationarity of the real oil price.

27. A second lag was insignificant and the inclusion of this second lag in the regression equation had almost no impact on the two other estimated coefficients. LM tests for first through fourth order serial correlation could not reject the hypothesis of no serial correlation. Separate tests that the errors have skewness and kurtosis coefficients equal to those of a normal distribution cannot be rejected at 5 percent, while a Jarque-Bera test cannot reject normality at 1 percent.

110,000 values from a normal distribution with standard deviation equal to the standard error (.2999) of regression equation (10). Using these generated random numbers and the log of the average real petroleum price for the 1972 to 2011 period as the starting value for p_{t-1} (3.671), the specification given in equation (10) is used to create 1000 series for p_t of length 110 periods.[28] These generated log prices are then converted to levels. To allow for up to ten lags to be employed in the analysis of the moving average-based stabilization funds, the simulations use the 11th element of each generated price series as the initial period price. The 1000 generated price series are used to create two sets of 1000 resource revenue series—one set for the depletion scenario and one for the non-depletion scenario. These resource revenue series are combined with non-stochastic non-resource revenue to generate 1000 government revenue paths under each of the two production scenarios. Given these revenue paths, we calculate government expenditure paths for each permutation of the four different types of stabilization funds as well as for the baseline case in which expenditure equals revenue in every period.

In the non-depletion scenario, resource production is constant and the quantity of production that accrues to the government through the tax is normalized to z, where $0 < z < 1$. Non-stochastic non-resource revenue is set equal to 1-z multiplied by the long run value of the resource price, $\bar{P}$, where $\bar{P}$ is the exponential of the value to which the process (equation (10)) for the natural log of the resource price, p, converges. Specifically, government revenue in period t is given by:

$$R_t = R_t^O + R_t^{NR} = (1-z)\bar{P} + zP_t, \tag{11}$$

where P_t is the value of the simulated petroleum price in period t. Resource revenue comprises, on average, a share z of total government revenue. Initially we set z equal to 0.5, but we also examine whether the results are robust when z equals 0.25. A share of resource revenue in total government revenue of 50 percent is substantial, but not unreasonable. The IMF (2012) finds that government revenue from extractive industries (oil, gas, and mining) is over 50 percent of total revenue for 22 of 57 resource-rich countries based on information for 2001–2010.

As noted above, the future path of resource revenue is unknown because the future price of the resource (P) is uncertain. For simplicity, the resource price is assumed to be stochastic for 100 periods only (periods 0 through 99), after which it becomes constant and equal to $\bar{P}$. This implies that, under the non-depletion production scenario, the sum of government resource and non-resource revenue from period 100 onwards is $R_t^O + R_t^{NR} = (1-z)\bar{P} + z\bar{P} = \bar{P}$. This specification incorporates a sufficiently long period of resource price uncertainty to make comparisons of the stabilization funds useful, while making the calculation of the welfare gain manageable.

In the depletion scenario, for periods 0 through 49, production is constant, so resource revenue is the same as under the non-depletion scenario. Beginning in period 50, resource production begins to decline at a linear rate, with the quantity of the resource accruing to the government through the production tax falling to zero in period 100. Thus, by period 100, the resource has been fully depleted and production tax revenue equals zero, so the price of the resource becomes irrelevant. From this period onwards, government resource plus non-resource revenue equals non-

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28. A similar methodology is used by Bartsch (2006). For each of the 1000 generated log real oil price series of length 100, the mean, standard deviation, and coefficients of skewness and kurtosis are calculated. The averages of the standard deviation and skewness measures of the simulated prices are quite similar to those of the actual 1972 to 2011 prices. On the other hand, the average of the simulated series is slightly higher and the average kurtosis value of the simulated series (2.75) is closer to that of a normal distribution than is the kurtosis coefficient for the actual data (2.41).

stochastic non-resource revenue only, $(1-z)\bar{P}$. Although the period in which revenue is stochastic is finite in length under both production scenarios, the horizon over which welfare is evaluated is infinite since the non-stochastic component of revenue continues forever.

At the end of period 99, a stock of assets (A_{99}) has been accumulated (equation (2)). The magnitude of this stock will differ across simulations as well as across production scenarios. Beginning in period 100, government expenditure for each simulation is set equal to the constant annuity $((r/(1 + r))A_{99})$ that can be financed with the assets accumulated by the end of period 99 for that simulation plus the sum of resource and non-resource revenue: $\bar{P}$ for the non-depletion case and $(1-z)\bar{P}$ for the depletion scenario. Since each of the 1000 simulations for each stabilization fund generates a different level of assets at the end of period 99 and, therefore, a different level of annuity, each simulation yields a different level of constant government spending from period 100 onwards even though resource revenue is constant, non-stochastic and identical across simulations.

4. STABILIZATION FUND PERFORMANCE

In this section, we compare the relative welfare performance of the four types of stabilization funds described in Section 2. Each of these funds has multiple variants that depend on the choice of fund-specific parameters, such as deposit rates, withdrawal rates, and moving-average length. Welfare also varies with parameter choices, such as the coefficient of relative risk aversion and the discount factor. To keep the discussion of the results manageable, we begin with a set of commonly used benchmark parameters: the coefficient of relative risk aversion, γ, is set equal to 2;[29] the real interest rate, r, is assumed to equal 0.03,[30] and, as is typical, we assume the discount rate, ρ, equals the real interest rate. In Section 4.3, we examine the robustness of the results by varying these benchmark parameters.

4.1 The *Perfect Foresight* Case and Fund Sustainability

To put the results in perspective, we begin by comparing the baseline policy of spending all revenue as it is received to the (unattainable) perfect foresight optimal expenditure path. The value of τ in the perfect foresight case provides an upper bound on the possible values of τ for each of the rules considered. In the perfect foresight case, the actual revenue path is revealed in the first period, so the government knows it will be able to choose the optimal expenditure path for the one revenue path that becomes the actual path out of the 1000 potential paths. Given the equality of the real interest rate and the discount rate, the optimal perfect foresight path is one in which government expenditure is constant. That is, the government spends the "permanent income" from the resource in each period. The value of τ in this case equates the expected utility of the perfect foresight path to the expected utility of the baseline expenditure path. For the non-depletion production scenario, τ is 5.31, while for the depletion scenario τ is 8.11 (Table 1, column (1), row 1

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29. See, for example Arrau and Claessens (1992), Durdu, Mendoza, Terrones (2009), Ghosh and Ostry (1997), Bartsch (2006), and Borensztein, Jeanne, Sandri (2009).

30. We assume all funds earn the same return, so differences in the pattern of withdrawals do not affect investment returns. A value of 3 percent is similar to the average *ex post* real interest rate on three-year (2.68 percent) and 10-year (3.33 percent) US government bonds over the period 1972 to 2011. The *ex post* real interest rate is calculated as the difference between the nominal government bond yield and the actual US GDP deflator-based inflation rate (from the US Bureau of Economic Analysis). Use of the PCE deflator yields almost identical real interest rates. The bond yields employed are the constant maturity Treasury bond yields from the Federal Reserve Board's H15 database.

Table 1: Comparison of the Welfare Gain (τ) for Selected Stabilization Funds

A. No Resource Depletion	$\gamma=2$ $r=0.03$ $\rho=0.03$ $z=0.5$	$\gamma=2$ $r=0.02$ $\rho=0.02$ $z=0.5$	$\gamma=4$ $r=0.03$ $\rho=0.03$ $z=0.5$	$\gamma=4$ $r=0.02$ $\rho=0.02$ $z=0.5$	$\gamma=2$ $r=0.03$ $\rho=0.03$ $z=0.25$	
Stabilization Fund	(1)	(2)	(3)	(4)	(5)	
1. Perfect foresight.	5.31	5.03	9.39	8.92	1.51	
2. *Fixed deposit* (d)–*fixed withdrawal* (w) fund, $d=0.5$, $w=0.1$, 10-year transition	**1.63**	1.85	**2.46**	2.89	**0.50**	
3. *Moving average* (MA) fund, 10-year MA, asset cap 10 times long run revenue, borrowing constraint	1.47	1.74	2.30	2.66	0.41	
4. *Revenue band* fund, borrowing constraint, 10-year moving average, 20% revenue band width	1.46	**1.99**	2.37	**3.05**	0.43	
5. *Rainy day* fund, 10-year moving average, borrowing constraint, 15% of resource revenue saved	1.37	1.48	2.18	2.35	0.41	
B. Resource Depletion	$\gamma=2$ $r=0.03$ $\rho=0.03$ $z=0.5$ $y=50$	$\gamma=2$ $r=0.02$ $\rho=0.02$ $z=0.5$ $y=50$	$\gamma=4$ $r=0.03$ $\rho=0.03$ $z=0.5$ $y=50$	$\gamma=4$ $r=0.02$ $\rho=0.02$ $z=0.5$ $y=50$	$\gamma=2$ $r=0.03$ $\rho=0.03$ $z=0.25$ $y=50$	$\gamma=2$ $r=0.03$ $\rho=0.03$ $z=0.5$ $y=25$
Stabilization Fund	(1)	(2)	(3)	(4)	(5)	(6)
1. Perfect foresight.	8.11	10.61	15.52	19.42	2.00	9.44
2. *Fixed deposit* (d)–*fixed withdrawal* (w) fund, $d=.5$, $w=.05$, 10-year transition	**4.34**	5.31	**8.72**	9.51	1.02	**6.08**
3. *Moving average* (MA) fund, 10-year MA, asset cap 10 times long run revenue, borrowing constraint	4.20	3.58	8.25	5.96	1.00	3.22
4. *Revenue band* fund, borrowing constraint, 10-year moving average, 20% revenue band width	4.33	4.20	8.35	7.21	**1.04**	3.34
5. *Rainy day* fund, 10-year moving average, borrowing constraint, 25% of resource revenue saved	3.36	**7.00**	7.33	**13.05**	0.71	3.55

Notes: The table entries indicate the value of τ, the maximum annual share of government expenditure, or the "tax" rate, that the representative agent would be willing to give up to have the expenditure stream given by the stabilization fund indicated rather than the expenditure stream given by equating expenditure to revenue in every period. The stabilization funds included are the versions of each type of fund that yield the highest welfare.

The parameter γ is the coefficient of relative risk aversion; ρ is the discount factor; r is the real interest rate; z is the average resource revenue share in total revenue; y is the number of years before depletion of the resource begins (applies in the resource depletion case only).

Bold-underline type indicates the largest value in each column excluding the perfect foresight case.

in parts A and B). These results imply, for example, that, under the resource depletion scenario, the representative consumer would be willing to sacrifice 8.11 percent of government expenditure in every period to obtain the smooth perfect foresight expenditure path rather than the path associated with a policy of spending all revenue as it is received.

Table 2: Debt or Assets Accumulated by Unconstrained Funds in the Non-depletion Scenario

	Multiple of long run government revenue	Percentage of the 1000 simulations where debt or assets accumulated exceeds 5 or 10 times long run government revenue after the following number of years:			
		25	50	75	100
1. Constant expenditure equal to long run average government revenue	5 times	39.2	72.6	86.9	94.1
	10 times	11.5	48.5	74.4	88.0
2. *Moving average* (MA) fund, 10-year MA	5 times	7.6	29.7	61.5	81.5
	10 times	0.3	4.7	29.1	62.7
3. *Revenue band* fund, 10-year moving average, 20% revenue band width	5 times	4.3	25.9	58.6	80.7
	10 times	0	3.2	26.9	60.1
4. *Rainy day* fund, 10-year moving average, 15% of resource revenue saved	5 times	0.9	10.2	40.8	66.4
	10 times	0	1.0	10.6	44.1
5. *Fixed deposit (d)–fixed withdrawal (w)* fund, $d = .5$, $w = .1$, transition	5 times	6.5	13.9	16.6	17.2
	10 times	0	0	0	0

An alternative rule with less demanding information requirements than the unattainable perfect foresight path equates expenditure in every period to the value to which the stochastic process for government revenue converges in the non-depletion case, $\bar{P}$. Any revenue exceeding this level of expenditure is saved in a fund, while borrowing or the assets in the fund support expenditure if revenue falls below this average. With this expenditure strategy, revenue can differ significantly from expenditure for long periods due to the volatility and slow mean reversion of petroleum prices.[31] As a result, considerable debt or asset accumulation can result. Table 2, part 1 shows that, with expenditure held constant at long run average revenue ($\bar{P}$), by the 25th period, in 39.2 percent of the 1000 simulations, the debt or assets accumulated by the government would exceed five times $\bar{P}$. By the 50th period, this percentage rises to 72.6 percent, with almost fifty percent of the simulations leading to debt or asset stocks of over 10 times long run average revenue. In some of the simulations, so much debt is accumulated by the end of 100 periods that total government revenue is insufficient to cover debt interest costs, implying a negative value for government expenditure after period 99.

Accumulation of debt equal to five times or more of average government revenue is infeasible for most countries. It would imply debt equal to 125 percent of GDP in a country where government revenue is a quarter of GDP. Many commodity exporters have limited access to international capital markets, so debt accumulation on this scale is likely to be unattainable. Further, a fund that accumulates a very large asset stock may be politically unsustainable since it can lead to pressure on the government to distribute more assets than stipulated by the fund's withdrawal criteria or to reduce the contribution rate, particularly during an economic slowdown. Hence, a fixed expenditure rule, while simple if the true stochastic process for revenue is known and stationary, is likely to be impractical for most resource producers.

31. Hamilton (2009) finds that petroleum prices exhibit weak mean reversion, so price changes tend to be quite persistent. This is consistent with the estimates given in equation (10). Oil price shocks are also quite large. For the period 1972 through 2011, the standard deviation of annual real petroleum prices in US dollars was 54 percent of the mean price.

The *moving average* fund also tends to accumulate infeasible quantities of debt and assets. For example, after 25 years 7.6 percent of the simulated revenue streams produce stocks of debt or assets that exceed average revenue by at least a multiple of five (Table 2, part 2). By period 50, this proportion rises to almost 30 percent, with 5 percent of the simulations yielding debt or asset stocks that exceed revenue by at least 10 times. The *revenue band* fund accumulates debt and asset stocks almost as quickly as the *moving average* fund (Table 2, part 3.) Debt or asset accumulation is not as rapid with the *rainy day* fund, but this fund can also lead to significant accumulation of debt or assets after 75 periods (Table 2, part 4). The excessive accumulation of assets and debt by these three types of funds is likely to cause them to be unsustainable under many possible revenue paths, leading to their abandonment.

The fundamental reason for significant debt or asset accumulation with the *moving average*, *revenue band* and *rainy day* funds is that, as with the fixed expenditure rule, these funds do not incorporate feedback from the stock of debt or assets to current expenditure. Theoretical and empirical studies show that fiscal rules with sufficiently strong feedback mechanisms tend to be stabilizing (Bohn, 2007; Budina and Wijnbergen, 2007; Wijnbergen and Budina, 2011; Celasun, Debrun and Ostry, 2007).

In contrast to the other three funds, the *fixed deposit–fixed withdrawal* fund does not accumulate debt, nor does it exhibit indefinite asset accumulation since, for a constant revenue stream, assets converge to $d/[1-(1+r)(1-w)]$ for each dollar of resource revenue.[32] This type of fund explicitly incorporates feedback from the asset stock to current expenditure—the amount withdrawn from the fund is larger (smaller) when the stock of assets is larger (smaller). As a result, in none of the simulations in Table 2, part 5, where $d = 0.5$, $w = 0.1$ and $r = 0.03$, does the debt or asset stock exceed 10 times average long run resource revenue. Therefore, in contrast to the three other funds, this fund is unlikely to be abandoned as a result of the excessive accumulation of assets or debt.

4.2 A Comparison of the Funds

4.2.1 A moving average *stabilization fund*

As noted above, a *moving average* fund without feedback is likely to be unsustainable for many revenue paths. One method of preventing the accumulation of excessive debt is to introduce feedback from the asset stock to expenditure through the imposition of a borrowing constraint. A borrowing constraint is not unrealistic since, for many commodity producers, when resource revenue falls and access to financial markets is required, financing in these markets is least available.[33] While a borrowing constraint prevents excessive debt accumulation, it does not inhibit asset accumulation. One method of restricting asset accumulation is to impose an asset cap. We consider asset caps equal to 2, 5, and 10 times long run average government revenue ($\bar{P}$). Once the cap is reached, all revenue is spent and the fund no longer smoothes expenditure.

32. For example, if the deposit rate (d) is 0.5, the withdrawal rate (w) is 0.1, and the interest rate (r) is 0.03, assets in the fund converge to 6.8 times resource revenue, while if d, w and r are, respectively, 1.00, 0.05 and 0.03, assets converge to 46.5 times revenue.

33. Daniel (2001) argues that petroleum exporters find it hardest to raise financing when the petroleum price plummets. For example, despite its petroleum wealth, Nigeria has limited access to international capital markets (Bartsch, 2006).

Table 3: The Welfare Gain (τ) for a *Moving Average* Fund with a Borrowing Constraint

A. No Resource Depletion

Asset cap multiple	Moving Average Length				
	2 years	3 years	5 years	7 years	10 years
no cap	0.29	0.53	0.86	1.07	1.27
2	0.05	0.15	0.26	0.35	0.51
5	0.29	0.53	0.84	1.03	1.22
10	0.29	0.55	0.92	1.18	**1.47**

B. Resource Depletion

Asset cap multiple	Moving Average Length				
	2 years	3 years	5 years	7 years	10 years
no cap	1.83	2.33	3.05	3.55	4.08
2	0.97	0.93	0.79	0.72	0.75
5	1.85	2.30	2.80	2.98	3.01
10	1.84	2.35	3.12	3.67	**4.20**

See the notes to Table 1.

Calculations assume a coefficient of relative risk aversion of 2, an interest rate of 0.03 and a discount rate of 0.03. The share of average resource revenue in total government revenue, z, is 0.5. For part B, depletion begins after 50 years.

The asset cap is calculated as a multiple of long run government revenue in the non-depletion case. If assets exceed this cap, government spending rises in the current period by the extent of the excess.

The borrowing constraint implies that, if assets are insufficient to finance expenditure at the level implied by the moving average, expenditure equals revenue plus any assets in the fund.

Table 3 reports the welfare benefit of a *moving average* fund relative to the baseline of spending all revenue as it is received. For the non-depletion production scenario with a borrowing constraint, but no asset cap, the best *moving average* fund incorporates a 10-year moving average and yields a relative welfare benefit of 1.27 (Table 3).[34] It is not surprising that the 10-year moving average yields the highest welfare as the longer moving average length facilitates greater expenditure smoothing. For both the depletion and non-depletion scenarios, a 10 times asset cap yields higher welfare than no cap, although not always by a large magnitude, and no cap generally yields higher welfare than a 2 or 5 times asset cap. Specifically, for the non-depletion case, τ reaches 1.47 with a 10 times asset cap, but is only 0.51 with a 2 times asset cap and 1.22 with a 5 times cap. The larger asset cap means only outlier asset trajectories are constrained.

With depletion of the resource, the absence of an asset cap has less of a negative impact on welfare because the fall in resource production that begins in the 50th period causes resource revenue to decline, which provides less opportunity for the accumulation of excessive quantities of assets. Nevertheless, as in the non-depletion case, welfare is highest with the 10-year moving average and the 10 times asset cap, although the gain from a cap relative to the no-cap case is small.

4.2.2 The revenue band and rainy day funds

As shown in Table 2, for many revenue paths, the *revenue band* and *rainy day* funds accumulate large stocks of debt and assets. Since the accumulation of a large debt stock is likely

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34. The potential welfare gain from stabilizing government expenditure is large, but not out of line with the range of estimates from studies that examine consumption volatility. Barro (2009) finds that the amount society would be willing to pay to eliminate the consumption volatility associated with typical economic fluctuations in the US is 1.5 percent of GDP, although this estimate is larger than that of Lucas (2003).

Table 4: The Welfare Gain (τ) for a *Revenue Band* Fund with a Borrowing Constraint

A. No Resource Depletion

Revenue band width (%)	Moving Average Length				
	2 years	3 years	5 years	7 years	10 years
10	0.47	0.70	1.01	1.22	1.41
20	0.56	0.77	1.07	1.27	**1.46**
50	0.47	0.64	0.89	1.07	1.25

B. Resource Depletion

Revenue band width (%)	Moving Average Length				
	2 years	3 years	5 years	7 years	10 years
10	2.18	2.62	3.28	3.76	4.25
20	2.43	2.82	3.42	3.86	**4.32**
50	2.59	2.91	3.40	3.76	4.14

See the notes to Tables 1 and 3.

Table 5: The Welfare Gain (τ) for a *Rainy Day* Fund with a Borrowing Constraint

A. No Resource Depletion

Fraction of Revenue saved for a rainy day	Moving Average Length				
	2 years	3 years	5 years	7 years	10 years
0.05	0.13	0.18	0.25	0.32	0.40
0.15	0.18	0.48	0.88	1.12	**1.37**
0.25	−3.57	−3.07	−2.32	−1.81	−1.33
0.50	−19.94	−19.42	−18.60	−18.02	−17.44

B. Resource Depletion

Fraction of Revenue saved for a rainy day	Moving Average Length				
	2 years	3 years	5 years	7 years	10 years
0.05	0.12	0.16	0.22	0.28	0.35
0.15	2.92	2.96	2.97	2.96	2.99
0.25	1.15	1.61	2.32	2.83	**3.36**
0.50	−12.74	−12.23	−11.41	−10.79	−10.12

See the notes to Tables 1 and 3.

to render these funds unsustainable, we impose a borrowing constraint when evaluating both these funds. The results in Table 4 show that the *revenue band* fund that yields the highest welfare has a band width of 20 percent. Nevertheless, a narrower band yields almost the same level of welfare so, particularly in the depletion case, the precise choice of band width is not crucial. Relative to a *moving average* fund with a borrowing constraint and no asset cap, the *revenue band* fund yields higher welfare in both the depletion and non-depletion cases. Even when the *moving average* fund is augmented with a 10 times asset cap, the *revenue band* fund yields almost the same level of welfare in the non-depletion case and yields higher welfare in the depletion case.

The Table 5 results show that the *rainy day* fund savings rate that yields the highest level of welfare depends on the production scenario. For the depletion case, the highest level of welfare requires a 25 percent saving rate. With non-depletion, the saving rate that yields the highest welfare

Table 6: The Welfare Gain (τ) for the *Fixed Deposit–Fixed Withdrawal* Fund with a 10-year Transition

A. No Resource Depletion

Withdrawal Rate (*w*)	Deposit Rate (*d*)				
	10%	25%	50%	75%	100%
5%	0.67	1.14	0.70	−1.21	−4.78
10%	0.64	1.28	**<u>1.63</u>**	1.12	−0.32
25%	0.46	0.98	1.49	1.56	1.20
50%	0.30	0.65	0.99	1.06	0.85

B. Resource Depletion

Withdrawal Rate (*w*)	Deposit Rate (*d*)				
	10%	25%	50%	75%	100%
5%	1.65	3.29	**<u>4.34</u>**	3.63	1.14
10%	0.89	1.89	2.80	2.84	1.99
25%	0.48	1.05	1.67	1.89	1.73
50%	0.29	0.64	1.02	1.16	1.05

See the notes to Tables 1 and 3.

is only 15 percent, while a 25 percent saving rate would reduce welfare relative to the baseline ($\tau < 0$). As a consequence, it may be difficult to choose the appropriate savings rate for this type of fund. In any case, the best version of the *rainy day* fund yields lower welfare in both the non-depletion and depletion cases than the *moving average* fund with a 10-times asset cap or the *revenue band* fund.[35]

4.2.3 A stabilization fund with a fixed deposit and fixed withdrawal rate

Table 6 presents the welfare gain of a *fixed deposit–fixed withdrawal* fund, relative to the baseline, for different deposit and withdrawal rates. The results in this table are for a fund where the deposit rate is increased to the desired deposit rate in 10 equal annual percentage point increments. Without this transition, because the fund begins with no assets, so withdrawals are small relative to deposits, the introduction of this fund can lead to a large initial drop in government spending. The transition smoothes the expenditure path by preventing an immediate large decline in expenditure following the establishment of the fund and, thus, raises welfare relative to the non-transition case.[36]

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35. If the stochastic price portion of the simulation period is extended in the non-depletion case to 200 periods from 100 periods, the *revenue band* and *rainy day* funds, as well as the *moving average* fund without an asset cap, tend to have much lower values for τ since, over a longer simulation period, more cases arise for these funds in which assets reach very high levels. In these cases, current spending is low and future spending is high, while a smooth expenditure path over time is preferred.

36. The best deposit and withdrawal rates are the same whether or not there is a transition. Even without a transition, with a 50 percent deposit rate, for example, the *net* deposit rate (deposits minus withdrawals) would equal 50 percent only in the first year following the establishment of the fund. With a 10 percent withdrawal rate (and, for simplicity, a constant income stream and zero interest rate), by the second year, net deposits would fall to 45 percent, would be 40.5 percent in the third year, 36.5 percent in the fourth year and would fall below 10 percent by the 17th year. The principal benefits of a transition are that the *net* deposit rate never reaches the fixed deposit rate, even in a single year, and the net deposit rate rises gradually before declining. For example, with a 10-year transition, a 50 percent deposit rate and a 10 percent withdrawal rate, the *net* deposit rate would never exceed 33 percent of resource revenue, with the maximum rate reached in the 10th year, and net deposits would fall below 10 percent after 22 years.

As shown in Table 6, in the non-depletion case, the maximum welfare gain is equivalent to 1.63 percent of annual government expenditure when 50 percent of natural resource revenue is deposited in the fund and 10 percent of the assets in the fund are withdrawn each year.[37] In the depletion scenario, the maximum welfare gain rises to 4.34 and also occurs with a deposit rate of 50 percent, although the best withdrawal rate falls to 5 percent. For both the depletion and non-depletion scenarios, the *fixed deposit–fixed withdrawal* fund yields a higher welfare gain than any of the other three types of funds (Table 1, column (1)).

An understanding of the high ranking of the *fixed deposit–fixed withdrawal* fund can be drawn from the results in Table 7. This table gives the average, over the 1000 simulations, of the standard deviation of government spending for the first 100 periods (the time frame for which petroleum prices are stochastic); average government spending during the first 100 periods; and average government expenditure for the remaining periods. For both the depletion and non-depletion simulations, the *fixed deposit–fixed withdrawal* fund yields the smallest or close to smallest standard deviation of government expenditures. In addition, for both production scenarios, this fund generates the highest level of government spending during the first 100 periods of the simulation. Finally, for the non-depletion case, the *fixed deposit–fixed withdrawal* fund yields almost identical government spending across the stochastic and non-stochastic revenue periods, and so raises welfare by smoothing spending.[38]

While a *fixed deposit–fixed withdrawal* stabilization fund can yield large welfare benefits, as is clear from the results in Table 6, this fund may also yield lower welfare than a policy of spending all current revenue as it is received. This happens in the non-depletion case if the deposit rate is sufficiently high and the withdrawal rate sufficiently low, so the fall in government expenditure in the early years of the fund's existence is large. Intuitively, in the non-depletion case, if resource prices are constant, it is optimal to spend all revenue every period since this strategy completely smoothes expenditure. When prices are variable, some saving is useful for stabilization and precautionary purposes and, with depletion, more saving is needed to finance consumption once the resource is exhausted. As shown in Table 6, a fund with a 100 percent deposit rate and 5 percent withdrawal rate, a close approximation to the fund used by Norway, *reduces* welfare by 4.78 percent relative to the baseline of spending all revenue as it is received if there is no resource depletion. For the case with depletion, the welfare gain for a fund that has a 100 percent deposit rate and 5 percent withdrawal rate is positive, at 1.14, but since depletion and the associated benefit from saving occur 50 years in future, this is a fraction of the 4.34 gain that accrues with a 50 percent deposit rate.

4.3 Robustness to Changes in the Simulation Parameters

As shown in Table 1, column (1), for the benchmark parameters, the *fixed deposit–fixed withdrawal* fund yields the highest welfare gain in both the depletion and non-depletion cases. To

37. Our finding that the greatest gains result from the *fixed deposit–fixed withdrawal* fund, a fund that ties expenditure to accumulated assets, is consistent with the results in Engel, Neilson and Valdés (2011). They find that the best rule puts less weight on future revenue forecasts and more emphasis on revenue obtained from accumulated savings. In particular, using simulations designed to model the Chilean economy, the greatest welfare gains are obtained when, in each period, approximately 12 percent of fund assets are withdrawn and 67 percent of "structural" income is saved, where "structural" income is the best estimate of average income over the next decade, based on past and current income.

38. The common non-stochastic component of revenues following period 100 is given by the level of the log value to which the price process given by equation (10) converges (43.9). For the first 100 periods, the simulated petroleum prices are generated from the stochastic process in the natural logs of the price and then converted to levels. Since the log of the price series is normal, the mean of the price series in levels (46.9) is higher than value to which the log price process converges when it is converted to levels (43.9).

Table 7: Selected Outcomes for the Best Funds in the Benchmark Case

A. No Resource Depletion	Value of τ (1)	Average standard deviation of the log of government spending (2)	Average government spending per annum during the first 100 years (3)	Average government spending per annum in the balance of the sample (4)
Stabilization Fund				
1. *Fixed deposit* (*d*)–*fixed withdrawal* (*w*) fund, $d = .5$, $w = .1$, 10-year transition	**1.63**	0.186	49.3	49.0
2. *Moving average* (MA) fund, 10-year MA, asset cap 10 times long run revenue, borrowing constraint	1.47	0.214	48.6	55.8
3. *Revenue band* fund, borrowing constraint, 10-year moving average, 20% revenue band width	1.46	0.181	46.1	67.9
4. *Rainy day* fund, 10-year moving average, borrowing constraint, 15% of resource revenue saved	1.37	0.202	46.6	55.5
5. Balanced budget (revenue = expenditure)	0	0.250	46.9	43.9
B. Resource Depletion				
1. *Fixed deposit* (*d*)–*fixed withdrawal* (*w*) fund $d = .5$, $w = .05$, 10-year transition.	**4.34**	0.166	46.0	30.2
2. *Moving average* (MA) fund, 10-year MA, asset cap 10 times long run revenue, borrowing constraint	4.20	0.219	42.2	31.4
3. *Revenue band* fund, borrowing constraint, 10-year moving average, 20% revenue band width	4.33	0.240	40.8	38.7
4. *Rainy day* fund, 10-year moving average, borrowing constraint, 25% of resource revenue saved	3.36	0.236	39.0	70.6
5. Balanced budget (revenue = expenditure)	0	0.300	40.5	21.9

See the notes to Table 1.

The benchmark case is from Table 1, column 1.

The petroleum price that determines government revenues is stochastic for the first 100 periods and then becomes non-stochastic.

The numbers indicated in columns (2)-(4) show the average values across the 1000 simulations.

The values in columns (3) and (4) are not discounted.

check the robustness of this result, we report in Table 1, columns (2)–(6), the values of τ for alternative simulation parameters. Specifically, we raise the coefficient of relative risk aversion from 2 to 4, as in Barro (2009); we reduce the discount rate and interest rate from 3 percent to 2 percent; we reduce the share, z, of resource revenue in total government revenue to 25 percent from 50 percent; and finally, to evaluate the significance of the depletion path assumption, we assume depletion of the resource begins after 25 years rather than 50 years.

For all permutations of the parameters, the funds in Table 1 all raise welfare relative to the baseline of spending all revenue as it is received. Thus, the conclusion that a fund can raise welfare relative to the baseline is robust to variations in the simulation parameters. Further, when the parameter values are changed, the Table 1 results show that, of the four funds, the *fixed deposit*–

fixed withdrawal fund is the most consistently highly-ranked. This fund yields the highest welfare of the funds examined in six of the 11 cases, and is the second-ranked fund in the remaining five cases. The *revenue band* fund is the top-ranked in three cases, but is third ranked in four cases. The *rainy day* fund is top ranked in two cases, but fourth ranked in eight cases, while the *moving average* fund is never the top-ranked fund.

As would be expected, a comparison of columns (1) and (3), and (2) and (4), in Table 1 reveals that a higher value for the risk aversion parameter, γ, raises the benefit of a stabilization fund (all else unchanged). Higher risk aversion (a higher value of γ) means that a smoother expenditure path leads to a larger increase in welfare. Further, a higher γ means prudence increases which raises the benefit of precautionary saving through a stabilization fund. Nevertheless, a higher risk aversion parameter generally does not alter the ranking of the funds.

Another characteristic of the results in Table 1 is that the welfare gains from the stabilization funds are two to three times as large in the depletion scenario as in the non-depletion case. In addition, the gains under the depletion scenario are quite large in magnitude, reaching almost 10 percent of government spending when the risk aversion parameter is 4 and the discount rate is 2 percent in the *fixed deposit—fixed withdrawal* case. These findings suggest that, when there is a significant fall in government revenue, as would be the case with depletion of a resource, there are major gains from smoothing government spending over time by saving in a fund.

A lower discount rate increases the value of future consumption, causing the benefit of saving to increase (all else equal). With a discount rate and interest rate of 2 percent rather than 3 percent, as in columns (2) and (4) of Table 1, the *revenue band* fund becomes the first-ranked fund in the non-depletion case, and the *rainy day* fund becomes top-ranked under depletion. On the other hand, the *rainy day* fund is fourth-ranked in the case of non-depletion and the *revenue band* fund is third-ranked with depletion, so the resource production scenario is key to the relative ranking of these funds. The effect of the lower discount rate on fund ranking depends on the extent to which the funds save in early periods and, therefore, can finance larger consumption in the future. For example, the best *rainy day* fund does well with a lower discount rate under depletion because it has a 25 percent saving rate, but it has only a 15 percent saving rate in the non-depletion case and so ranks less highly.[39]

In the benchmark case, we assume the share of resource revenue in total revenue, z, is 50 percent on average. When the share of resource revenue is reduced to 25 percent (Table 1, column (5)), the benefit of a stabilization fund, while still positive, declines to less than half of the level in the benchmark case. This suggests that, as would be expected, a stabilization fund is likely to be more beneficial to a country that is highly reliant on volatile resource revenue.

When depletion of the resource begins in 25 years rather than 50 years, there is a larger benefit of saving resource revenue to support future consumption, and less time to save. Table 1, Part B, column (6) shows that the 50 percent deposit rate and 5 percent withdrawal rate for the *fixed deposit–fixed withdrawal* fund yields the highest welfare gain. This is not surprising since this fund tends to build up savings quickly because the deposit rate is high and the withdrawal rate low. For example, the deposit rate is twice that of the *rainy day* fund. In addition, the fixed deposit rate means deposits are made every period, in contrast to the *moving average* and *revenue band* funds

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39. The ranking of funds with a 1 percent interest rate is identical to that for 2 percent. Ploeg and Venables (2011) argue that a higher interest rate may be more appropriate for developing countries. When the discount rate and interest rate rise from 3 to 4 percent, the *fixed deposit–fixed withdrawal* fund remains the highest-ranked fund in the case of no depletion, but becomes the second-ranked fund with depletion.

in which deposits are only made if certain conditions are met, so with these funds there may be long periods with no deposits.

The *fixed deposit–fixed withdrawal* fund with a 50 percent deposit rate and a 10 or 5 percent withdrawal rate is the best-performing fund in the benchmark case. A fund that performs well in different situations is more attractive as the design of the fund does not depend on precisely identifying the particular characteristics of a jurisdiction, nor need the fund be re-designed in response to every change in the environment. For this reason, we examined whether a fund with these deposit and withdrawal rates is the best performing *fixed deposit–fixed withdrawal* fund for all the parameter variations given in Table 1.[40] For the non-depletion scenario, the 50 per cent deposit and 10 percent withdrawal rate combination yields the highest welfare of the twenty deposit-withdrawal rate pairs given in Table 6 for all five of the parameter permutations of Table 1 except in one case in which it yields a τ value that is just 0.02 smaller than the best fund. For the depletion case, the 50 percent deposit–5 percent withdrawal fund continues to yield the highest welfare when the risk aversion parameter is increased to 4 as well as when the average share of resource revenues in total revenues falls from 0.50 to 0.25. When the interest rate falls to 2 percent or depletion begins in 25 years, as for the parameter combinations given in columns (2), (4) and (6) of Table 1, the best withdrawal rate remains at 5 percent, but the best deposit rate rises to 75 percent. A higher deposit rate would be expected in these two cases since a lower interest rate and discount rate cause future consumption to contribute more to welfare, and quicker depletion means more current saving is needed to smooth consumption over future periods. Nevertheless, in these cases, a fund with a 50 percent deposit rate yields the second highest level of welfare. These results indicate that the *fixed deposit–fixed withdrawal* fund with a 50 percent deposit rate and a 5 to 10 percent withdrawal rate attains among the highest welfare gains for the range of model parameters considered.

5. DISCUSSION AND CONCLUSIONS

A rule-based stabilization fund is one method of addressing government revenue volatility and uncertainty in resource-producing regions. While many jurisdictions have established revenue stabilization funds to smooth government expenditure, there is little evidence on whether these funds improve welfare or whether some fund designs increase welfare more than others. This study uses Monte Carlo analysis to evaluate the welfare performance of several different types of rule-based stabilization funds for a petroleum-producing region. The performance of stabilization funds is an important policy question since the adjustment of government expenditure to movements in revenue can be costly. Further, many stabilization funds that have been adopted in the past have been abandoned or frequently altered, so it is important to understand why this may have occurred.

Results presented above show that a stabilization fund can be a welfare-enhancing method of addressing highly volatile resource-price driven revenue. Some funds do much better than a policy of setting expenditure equal to current revenue. Further, the benefits of stabilization are likely to be greater than the amounts calculated here since our welfare measure does not include the costs of re-allocating resources (ie., hiring and firing costs) or the negative impact of volatility on investment and future growth. While there are welfare gains from the use of a rule-based stabilization fund, none of the funds replicate the welfare of the perfect foresight expenditure path. This follows because, given the high variability and persistence of petroleum price movements, even the best rule-based funds do not eliminate the volatility of government expenditure.

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40. Detailed tables of results are not reported to conserve space.

A fund that incorporates a fixed deposit rate out of current resource revenue and a fixed withdrawal rate out of the accumulated stock of fund assets, along with a gradual transition to the desired deposit rate, yields the highest welfare in both the resource depletion and non-depletion scenarios under the benchmark parameter values. An advantage of this *fixed deposit–fixed withdrawal* fund is that, by design, it incorporates feedback from the accumulated asset stock to current expenditure. This prevents the stock of assets from following an unsustainable path (and there is no problem with debt sustainability as this fund does not accumulate debt). When the parameters of the simulation are varied, this fund is the top-ranked fund in six of the eleven cases examined, and the second-ranked fund in all other cases. Finally, for the alternative sets of parameters considered, the fixed deposit and withdrawal rates that yield the highest welfare are relatively robust across the two resource production scenarios, in the sense that the best deposit rate is the same under both scenarios—50 percent—and the withdrawal rate is similar, although a bit lower in the resource depletion case—5 versus 10 percent. This characteristic is particularly helpful since it is not generally possible to determine if a resource stock is truly in decline (as there may be new discoveries).

These best deposit and withdrawal rates differ sharply from the rates for the best-known resource revenue stabilization fund - the *Norwegian Government Pension Fund*. While Norway's fund is also a *fixed deposit–fixed withdrawal* type fund, it features a very high 100 percent deposit rate and low 4 percent withdrawal rate. Even with a transition, a deposit rate of 100 percent combined with a withdrawal rate of 5 percent yields welfare "gains" per year of -4.68 percent and 1.14 percent of government spending in the non-depletion and depletion scenarios, respectively, values which are much lower than those associated with a smaller deposit rate and higher withdrawal rate (Table 6). The reason for the lower welfare of the Norwegian-type fund is that it accumulates a large stock of assets. While a large stock of assets benefits future generations, the accumulation of these assets leads to lower expenditure in earlier periods, which has a negative effect on welfare. Relative to the 50 percent deposit–10 percent withdrawal fund, a fund with a 100 percent deposit rate and a 5 percent withdrawal rate accumulates approximately seven times more assets.[41]

Funds that specify government expenditure to be constant and equal to the mean of the resource revenue distribution, or in which expenditure is based on a moving average of past resource revenue, have a high probability of accumulating infeasible levels of debt or assets. As a consequence, these funds are more likely to be abandoned. The key shortcoming of funds such as these is that they do not incorporate feedback from the stock of assets to expenditure, in contrast to *fixed deposit–fixed withdrawal* type funds. One method of incorporating feedback is to impose a borrowing constraint and an asset cap, but this complicates fund design and necessitates the choice of an appropriate cap.

The purpose of the funds considered in this study is to smooth government expenditure. Smoother expenditure should prevent pro-cyclical government spending in petroleum-producing jurisdictions from accentuating the business cycle and help stabilize the overall economy. An alternative objective is to choose the level of government spending to explicitly attempt to stabilize movements in output, employment, or other macroeconomic variables, such as the exchange rate.[42]

41. Norway is forecast to face rapid resource depletion and an aging population (Eriksen, 2006; Jafarov and Leigh, 2007; Harding and Ploeg, 2013), both factors that may make a larger fund more appropriate.

42. We do not consider how the allocation of fund assets, say to offshore investments, could have a stabilizing impact. For example, a larger share of resource revenue invested offshore might be more effective in preventing currency appreciation following a resource boom and, therefore, may better stabilize private sector activity.

A stabilization fund that incorporates counter cyclical expenditure of this type is likely to be much more complicated and challenging to implement. Further, a more complicated rule would be more difficult for the public to monitor and may introduce leeway for discretion that, in turn, could lead to greater volatility and the pursuit of an unsustainable fiscal plan.

The analysis above abstracts from political economy issues associated with the implementation of a stabilization fund, but these may make the *fixed deposit–fixed withdrawal* fund more attractive. The key advantage of the *fixed deposit–fixed withdrawal* fund is that it is quite simple and easy to communicate and understand. Clear and simple deposit and withdrawal criteria also give politicians less room for discretion, which could help insulate policymakers from short-term political pressures—say to increase spending during booms. Clarity and transparency embedded in fund design are also likely to facilitate monitoring by the public of politicians who may be inclined to alter spending according to the political cycle.[43] Further, a fund is more likely to be successful if it enjoys broad public support. Public support would be expected to be stronger if the fund is simple in design and transparent in operation, both of which are characteristics of a *fixed deposit–fixed withdrawal* fund.

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43. Ossowski, Villafuerte, Medas, and Thomas (2008, 24) argue that, while it is always possible for a government to circumvent a fund's spending rules, if budget papers treat government revenue as net of contributions to and withdrawals from the fund, this may at least foster an informed debate on fiscal policy choices.

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