Do Developing Countries Lose Money on Central Bank Intervention? The Case of Zambia in Copper-Market Boom and Bust

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Keywords: Intervention, Intervention Profits, Exchange Rates, Central Bank, Zambia

JEL Classifications: G12, G14, G15

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1. Introduction

Many developing countries adopted economic reform programs in the 1990s and 2000s, including many in sub-Saharan Africa (SSA). These programs generally contain exchange-market reforms, and a substantial share of the reforming countries adopted more flexible exchange rates. The fear of floating among less developed countries, however, is well-documented (Calvo and Reinhart 2002). Few of these countries adopted freely floating rates; most adopted managed floats. In an IMF survey in 2001, all developing countries’ central banks included in the survey acknowledged that they intervened in foreign exchange markets. Little information is available regarding the frequency and size of developing SSA country interventions. Knight (2006) reports from a roundtable discussion with central bankers from Africa that they differ on how tightly they manage their floats. Some intervene occasionally, others more actively. Over this paper's sample period, 1996-2009, shifts in economic fundamentals complicate analysis. From the early- and mid-2000s, increased commodity and agricultural prices have increased SSA incomes but also put appreciation pressure on these exporters' exchange rates. As concerns intervention, pressures shifted from selling dollars to buy domestic currency to accumulating dollars for domestic currency to keep the exchange rate from appreciating. Bilignaut et al. (2007) found that African countries increased their foreign exchange reserves substantially more than other developing countries during 2002 to 2006. The increase in reserves has continued; Mbeng Mezuri and Dung (2013) estimate that African countries on average held between $165.5b/yr and $193.6b/yr in excess reserves, which is more than the estimated infrastructure financing gap in Africa of $93b per year over 2001 to 2011.

In estimates below, this paper takes account of a regime shift for Zambia when the copper market went from bust to boom in the early 2000s.

One issue, widely discussed, is whether intervention affects the exchange rate in the direction the central bank desires, that is, whether intervention is effective. The results are mixed, and there is much debate over the econometric methods used; Appendix 1 presents a brief survey of studies, including countries covered, econometric methods and empirical results. Note that many studies use intervention data not publicly available. Another issue, the subject of this
paper, is whether central banks make losses (profits) on their intervention and if so, how much. As Cassino and Lewis (2012) argue, "Unprofitable intervention may damage the central bank’s credibility in financial markets, reduce the likelihood of future intervention and attract greater scrutiny from fiscal authorities and government…. [Profitable intervention] may also protect a central bank’s independence, as it avoids having to seek a recapitalization from the government." Neely (2000) reports that central bankers in conversation admit that they take the profitability of interventions into account when they think in terms of justifying themselves to their governments. In many countries, finance ministers dominate central banks; because finance ministers are almost always politicians, and central bank heads often are politicians, intervention losses can seriously damage political ambitions. This paper is the first to present estimates of central bank risk-adjusted intervention profits for an SSA country. The only previous estimate for a developing country is from Kulkarni's (2006) investigation of India: he finds that India makes losses, but he does not take into account adjustments for risk of the type discussed below; nor does he estimate profits arising from timing ability, the type of profits the BOZ might make.

On the one hand, some authors present estimates of large losses from industrialized country intervention, losses perhaps arising from fruitlessly fighting against the market or even central bank incompetence (Taylor 1982a,b). On the other hand, central banks have inside information of government policy and may be able to use this information to make profits, just as insiders might profit in stock markets. Indeed, one stream of thought is that the government might use intervention to signal policy changes, precisely the sort of intervention that central banks might use to make profits (Simatele and Sweeney 2015 discuss the signaling literature). Moreover, from an efficient markets perspective, a central bank might not be able to make risk-adjusted profits, but by the same token, it should on average not make losses (Sweeney 2000), aside from any needless transaction costs. The issue then is empirical.

This paper develops a model of risk-adjusted profits from intervention and applies it to estimate risk-adjusted profits from central bank intervention for Zambia, the only SSA country that makes intervention data publicly available. Perhaps remarkably, given the skepticism that central banks in industrialized countries can make profits, results below suggest that over the period 1996-2009, the Bank of Zambia (BOZ) made risk-adjusted profits of 5.8716% per year (or $19.0512m per year) in the higher estimate and 1.3516% per year (or $4.3853m per year) in the lower estimate. These estimates suggest that developing country central banks may be able to
carry out their intervention policies more skillfully than some observers think. The BOZ states that its aim is not to affect the exchange rate level or trend but to lean against the wind to smooth fluctuations around trend. Those developing country central banks that state they follow a leaning-against-the-wind strategy might be able to make intervention profits. Unfortunately, these other developing countries do make their intervention data available.

To be sure, these results for Zambia need not be representative. Developing countries are highly heterogeneous, in terms of region, income per capita, dependence on natural resources or agricultural staples, extent and frequency of intervention, and more. Zambia is, however, of interest as an SSA country, a low-income country and as an aid recipient. IMF classifies Zambia’s exchange rate regime as a de facto managed float, together with the SSA countries Angola, Burundi, Ethiopia, the Gambia, Ghana, Guinea, Kenya, Liberia, Mauritius, Nigeria, Rwanda, São Tomé and Príncipe. (Slavov 2013 also arrives at this classification). Further, copper is a major part of Zambia's exports, and results for Zambia might be useful in thinking about the many developing countries dependent on natural-resource or staple exports, though of course oil-exporting and agricultural-staples exporting countries have their own issues. Zambia may, however, be representative of SSA countries that undergo shifts in process in their major export markets, as Zambia did when the copper market went from bust to boom in the early 2000s. It would be highly useful to apply this paper's methods to other SSA countries; from talking with SSA central bankers and surveying central bank web pages, however, Zambia is the only SSA country that makes its intervention data publicly available.

This paper makes two contributions. First, on a technical level, it presents a superior method, relative to those in the literature, of estimating central bank risk-adjusted profits. Previous attempts at risk adjustment use so-called "mean adjustment" (Sweeney 1997, 2000, and Sjö and Sweeney 2000). This paper shows how to incorporate time-varying risk premia, and in the absence of estimates for risk premia, how to use an instrumental variables approach. It also shows how to take care of simultaneous equation bias, a bias that past attempts at profit measurement have not dealt with. In addition, we analyze how cumulative intervention relates to changes in log exchange rates, an important technical issue because cumulative intervention appears to be a non-stationary series that is integrated (or near-integrated) of order one, and changes in log exchange rates are stationary.
Second, this paper is the first to try evaluate the risk-adjusted intervention profits of a
developing country central bank. Zambia is of particular interest because it underwent an
important exogenous change. In the period 1996-2002, the world was in a copper-market bust,
with low prices and sluggish export demand. In the period 2003-2009, the world was largely in a
copper boom, though with a sharp break in prices in 2008 but a quick rebound. Our estimates
show that the BOZ makes positive and economically significant profits. This is evidence that
developing country central banks may be more sophisticated and better foreign-exchange market
managers than many observers think.

2. Review of the Literature

Making profits from foreign exchange interventions is a not formal goal for any central bank
in its statement of purposes. Typically central banks claim that their interventions are aimed at
welfare-enhancing goals from macro policy and micro regulation. In practice, however, it is
difficult for central bankers not to consider profits and losses; if the central bank makes
intervention losses, it is difficult to document to the government and public that intervention still
has positive economic benefits. Further, according to Neely (2000), central bankers in
classification admit that they take the profitability of interventions into account when they think
in terms of justifying themselves to their governments. International development bankers have
told the present authors of similar conversations with finance ministers and central bankers of
developing countries.

Friedman (1953) suggests evaluating the success of a central bank’s foreign-exchange
intervention by examining its profits from intervention—central bank intervention is stabilizing
if and only if the central bank makes intervention profits. Put another way, losses from
intervention suggest the central bank likely destabilizes the foreign-exchange market. The
argument that profits imply that intervention is stabilizing, and losses that it is destabilizing, is in
doubt. Authors have produced theoretical examples of profitable speculation that is destabilizing
or stabilizing but not profitable or that profit measures contain biases (Baumol 1957; Kemp
2001, Cassino and Lewis 2012). Further, if sterilized intervention has no effect on exchange
rates, as many argue, a central bank may make money on its intervention without stabilizing the
market (Leahy, 1989, 1995; Edison, 1993; Dominguez and Frankel, 1993). In the view of many
researchers, the issue is whether central banks lose money from intervention, not whether such
losses imply destabilization (Mayer and Taguchi 1983 suggest other approaches to whether
intervention is stabilizing).

In one view, central bank intervention should make expected positive profits: Central banks
might have an information advantage over other market participants; they also intervene to
straighten out destabilizing behavior such as "disorderly markets." In another view, government
interventions in markets are generally misguided and costly; the central bank should expect to
lose money by intervening in exchange markets dominated by intelligent, stabilizing speculators
(Taylor 1982a,b). Szakmary and Mathur (1997) find that speculative profits from trading rules
are strongly associated with losses from central bank intervention, as does LeBaron (1996). In
contrast, Neely (1998) argues that in fact central banks make profits. In a third view, the
exchange market should be efficient in the sense of the Efficient Markets Hypothesis (EMH),
and may well be strong-form efficient relative to central bank intervention, implying expected
intervention losses of zero (Sweeney 2000), aside from unnecessary transactions costs. Which
view most accurately characterizes exchange markets is then an empirical issue.

Taylor (1982a,b) argues that estimated central bank intervention losses are economically and
statistically significant (Schwartz, 1994, finds US intervention losses). Many authors question
Taylor's work on various grounds (see in particular Spencer 1985, 1989 and Taylor 1989).\footnote{An important debate on Taylor's work is between Spencer (1985, 1989) and Taylor (1989).} Estimated losses vary importantly, sometimes dramatically, across time periods (Wilson 1982,
Jacobsen 1983). Taylor (1982a) does not include interest-rate differentials in his calculations of
losses (but see his footnote 4, and Taylor, 1982b, 58-60, which both include interest earnings),
and their inclusion is sometimes important for results (Bank of England 1983, Leahy 1989, 1995,
Fase and Huijser 1989, Murray, Zelmer, and Shane 1989, Becker and Sinclair 2004; Beenstock
and Dadashi investigate central bank profits in forward markets intervention, implicitly involving
interest rates). Some authors use time periods chosen to make accumulated net intervention equal
to zero at the end of the period (Argy 1982, Bank of England 1983, Jacobsen 1983), though this
is a controversial restriction. Corrado and Taylor (1986) argue that this strategy underestimates
central bank losses; they base their argument on a case where intervention has temporary effects
on the exchange rate. Further, they argue more generally argue that appreciation and intervention
should be viewed as possibly interdependent; this argument suggests simultaneous equations bias
issues, but they do not attempt to deal with this bias. This paper is the first to correct for simultaneity bias in the context of profit estimates.

Most researchers do not adjust central bank intervention losses to reflect risk premium earned from taking exposed foreign-exchange positions. Further, few use the implications of the EMH in designing measures of profits and tests of the significance of estimated profits, or draw the conclusions for exchange-market efficiency of the estimates and significance of central bank intervention profits (to be sure, some authors offer exchange-market inefficiency as a possible explanation of positive measured profits, for example, Leahy, 1989, 1995). Sweeney (1997, 2000) and Sjö and Sweeney (2000, 2001) argue that previous studies err by not adjusting intervention profits for risk and present estimates showing that the Fed and the Swedish Riksbank may have made profits on their intervention and that at the least they did not make losses. Their risk adjustment is so-called mean adjustment, which is appropriate when risk premia are approximately time constant. The discussion in section 3 extends their methods to allow for time-varying risk premia. In addition, Section 3 presents an instrumental variables technique for estimating risk-adjusted profits when risk-factor realizations and premiums are not available.

The only other study of a developing country's intervention profits is Kulkarni's (2006) investigation of India. He finds that India makes losses, but he does not take into account adjustments for risk of the type discussed below.

Depending on data availability on intervention, studies use intra-day, daily, monthly or even quarterly data. Using Swiss data, Fischer (2003) studies differences in estimates of central bank profitability from intervention from using intra-day data through quarterly data. He concludes, "The empirical estimates show that the use of weekly or monthly data may be closer to the so-called ‘true’ estimates based on transactions data than is the case when daily data are used." This paper uses weekly BOZ data, the most detailed available, over the period 1996-2009.

During our sample period of managed float, the BOZ did not operate with a fixed target for the exchange rate. Chipili (2014) explains that the aim of intervention was to “achieve a stable and competitive exchange rate consistent with macroeconomic conditions.” Earlier studies of intervention in Zambia, Chipili (1998), Mwenda (1996), Mungule (2004), Simatele (2004) and Chipili (2013, 2014), focus on identifying the factors driving foreign exchange volatility and test
the effects of intervention on the volatility of the kwacha. The typical result is that intervention reduces volatility but that the economic significance seems to be small.

3. Shift in Process Driving the Exchange Rate

For Zambia, the world copper price and the export demand it faced behaved quite differently in the first sub-period, 1996-2002, compared to the second sub-period, 2003-2009. From Figure 1, the sample period 1996-2002 was one of copper market bust, with low copper prices (see the curve Cop); Zambia's exports of copper were also low. In contrast, the sample period 2003-2009 was one of copper market boom, with high copper prices and exports, though with a sharp break but fast recovery in 2008-2009. This paper does not attempt to model relationships among weekly changes in copper prices, changes in the exchange rate and intervention. Rather, it investigates how the possible shift in the process driving the copper market leads to shifts in the processes driving both the exchange rate and intervention, as Figure 1 suggests (see the curve $S_k$ for the number of kwacha per USD and the curve $C_I$, for the level of cumulative intervention).

For this reason, in addition to fitting a model for the whole period, this paper fits separate models for the two sub-periods. Total net sales of USD were 56% larger in the first sample period than the second (cumulative intervention of 613 over the first sample period, 314 over the second).

The descriptive statistics below compare monthly data for the two sub-periods ($\Delta \ln S_t$ is in percent per year). The Kwacha ($S$, number of kwacha per dollar) is more volatile in the first period, as measured by the standard deviation of $S$). The mean cumulative flow of aid is much the same in total (2,201 and 2,261), though aid is somewhat more volatile in the first half, as measured by the standard deviation of Aid. Copper prices ($C_{op}$) are much higher and more volatile in the second period (means of 1773 and 4901, and standard deviations of 297 and 2258). Interventions ($I$, net purchases of USD) are larger in the first period, but more frequent and volatile in the second period (means of -7.294 and -4.101, and standard deviations of 12.01 and 27.63). The BOZ sold in 46% of the weeks in the first sub-period, and bought in only 3.0%; in the second sub-period the BOZ sold in 42% of the weeks but bought in 45%. The BOZ sold 56% more USD in the first sub-period than the second (CI of -613 and -394).
Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>ΔlnS</th>
<th>Cop</th>
<th>I</th>
<th>Aid,</th>
<th>Cl,</th>
<th>ΣAid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Whole</td>
<td>3447.56</td>
<td>9.776</td>
<td>3385</td>
<td>-5.591</td>
<td>21.88</td>
<td>-1.006</td>
<td>4.463</td>
</tr>
<tr>
<td>First Half</td>
<td>2556.12</td>
<td>22.38</td>
<td>1773</td>
<td>-7.294</td>
<td>20.39</td>
<td>-6.13</td>
<td>2.201</td>
</tr>
<tr>
<td>Second Half</td>
<td>4339.00</td>
<td>0.175</td>
<td>4901</td>
<td>-4.101</td>
<td>23.56</td>
<td>-3.94</td>
<td>2.261</td>
</tr>
<tr>
<td>SD Whole</td>
<td>1281.02</td>
<td>15.77</td>
<td>2262</td>
<td>21.79</td>
<td>42.23</td>
<td>209.9</td>
<td>1.026</td>
</tr>
<tr>
<td>First Half</td>
<td>1154.41</td>
<td>16.23</td>
<td>297</td>
<td>12.01</td>
<td>46.00</td>
<td>70.8</td>
<td>368.0</td>
</tr>
<tr>
<td>Second Half</td>
<td>600.55</td>
<td>14.60</td>
<td>2258</td>
<td>27.63</td>
<td>37.70</td>
<td>133.7</td>
<td>544.9</td>
</tr>
</tbody>
</table>

No. Interventions selling USD buying USD non-zero zero total
Whole 79 (43.89%) 46 (25.56%) 125 (69.44%) 55 (30.56%) 180
First Half 39 (46.43%) 3 (2.57%) 42 (50.00%) 42 (50.00%) 84
Second Half 40 (41.67%) 43 (44.79%) 83 (86.46%) 13 (13.54%) 96

Sₜ is the number of kwacha per USD in the exchange market; ΔlnS is a continuously compounded percentage rates of change per year. Copₜ is the USD price of copper in tons. Iₜ is net intervention (net purchases of USD) in millions of USD. Clₜ is cumulative intervention, Clₜ = ΣIₜ. Aid is foreign aid inflows in millions of USD. No. Int. is the number of months with net interventions with various signs over the whole period and two sub-periods. Note: Over the whole period, the first sub-period and the second sub-period, the number of months in which aid occurred was 80.39% (164 of 204 months), 75.00% (81 of 108 months) and 86.46% (83 of 96 months).

Simatele and Sweeney (2015) explain and analyze how the BOZ used a substantial portion of aid to buy kwacha in the foreign exchange market, by selling U.S. dollars received in aid during the sub-period 1996-2002. Donor governments gave a large part of this aid as general budget support. In their analysis, this intervention was the obverse of, and required, by using aid to finance government programs. Further, as Figure 1 shows, this sub-period was one of copper market bust, with low prices and sluggish export demand, and copper is a large part of Zambia's exports. In Figure 1, for comparability with the exchange rate the cumulative intervention variable is sales of USD, not purchases as in the descriptive statistics above. The price of copper is USD per ton. The exchange rate Sₜ is the number of kwacha per USD. The data are normalized (demeaned and relative to standard deviation). It might appear that intervention failed, in that cumulative sales accompanied substantial increases in ZMK/USD. A good part of the intervention, however, was to convert aid to kwacha, as the government required to fund its programs. Nevertheless, though the BOZ had little control over its monthly or yearly sales, possibly the BOZ timed its intervention to make profits.

During the second sub-period, 2003-2009, the copper market boomed, but with substantial ups and downs, and a sharp break and rebound in 2008. The rate of kwacha depreciation fell in the second sub-period to 0.175%/yr from 22.38%/yr, which implies an appreciation of Zambia's real exchange rate, because consumer price inflation in Zambia ran at a rate of 12.56%/yr and world inflation rates were low. This appreciation may be a manifestation of the Dutch disease,
brought on by the copper boom. In the 96 months in the second sub-period, the BOZ intervened in 83, sales in 40 and purchases in 43. The purchases of dollars occur early in the sub-period, when the number of kwacha per dollar is falling or remaining stable while consumer prices rise; the sales of dollars occurred in the latter part of the period when the kwacha largely weakened. It should not be surprising, then, if parameters in the central bank intervention function shift between sub-periods, as section 5 discusses.

### Intervention Statistics

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>ΔlnSₜ</th>
<th>Copₜ</th>
<th>Iₜ</th>
<th>Aidₜ</th>
<th>CIₜ</th>
<th>ΣAidₜ</th>
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<tbody>
<tr>
<td>Mean</td>
<td>2003-2007</td>
<td>3518.75</td>
<td>0.008147</td>
<td>3385</td>
<td>-3.961</td>
<td>21.83</td>
<td>-370</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>2003-2007</td>
<td>1232.82</td>
<td>0.046428</td>
<td>2261</td>
<td>19.94</td>
<td>46.16</td>
<td>166.6</td>
</tr>
<tr>
<td></td>
<td>2008-2009</td>
<td>778.27</td>
<td>0.0540</td>
<td>1868</td>
<td>32.92</td>
<td>49.62</td>
<td>211</td>
</tr>
</tbody>
</table>

Cumulative intervention in second half

<table>
<thead>
<tr>
<th></th>
<th>CIₜ</th>
<th>date</th>
<th></th>
<th>CIₜ</th>
<th>date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-2007</td>
<td>-211.60 (start, maximum)</td>
<td>01/07/02</td>
<td></td>
<td>-353.14 (start)</td>
<td>01/07/08</td>
</tr>
<tr>
<td></td>
<td>-620.74 (minimum)</td>
<td>11/29/04</td>
<td></td>
<td>-320.14 (maximum)</td>
<td>05/26/08</td>
</tr>
<tr>
<td></td>
<td>-320.64 (interior minimum)</td>
<td>06/18/07</td>
<td></td>
<td>-880.14 (minimum)</td>
<td>11/30/09</td>
</tr>
<tr>
<td></td>
<td>-345.14 (end)</td>
<td>12/31/07</td>
<td></td>
<td>-865.14 (end)</td>
<td>12/07/09</td>
</tr>
</tbody>
</table>

### 4. Measuring Risk-Adjusted Profits from Central Bank Intervention

Observers typically divide the profits an investor makes into two components. The first arises from skill in picking the asset in which to invest ("stock picking"). Profits from this source are buy-and-hold profits—they arise from holding the asset rather than varying holdings of it over time. The second source of profits is timing ability, the ability to choose profitable times to increase and decrease holdings in the asset ("buy low, sell high"). Timing is the relevant source of profits or losses that the BOZ may make. The BOZ is tightly dependent on the government of Zambia (GOZ), as are central banks in most developing countries. It must buy and sell dollars over time as the GOZ tells it to. But the GOZ also instructs the BOZ to stabilize fluctuations in the exchange market. This gives the BOZ some discretion over when to buy or sell. In cases where it must sell dollars, the BOZ may have the skill to buy kwacha when it is relatively weak so each dollar sold generates more kwacha.

Let the rate of return on an exposed position in USD from t-1 to t be Rₜ. In more detail, profits Rₜ is the one-week appreciation rate of the dollar plus the deposit rate on the dollar less the deposit rate on the kwacha plus, or Rₜ = Δsₜ + (iₜusd,t-1 - iₜzmk,t-1), where iₜusd,t, iₜzmk,t and Δsₜ are the deposit rates and dollar appreciation rate all in continuously compounded terms, Δsₜ⁺ = ln(Sₜ⁺/Sₜ⁻)
was negative on average over the sample period, because on average the BOZ kwacha per dollar rose, that is, dollar appreciation was positive. Suppose that $R_4$ where $CI_1$ the dollar is gross profit on this decision if the risk exchange rate is $S_3$ in this section to define intervention as $CI (R^{*_{t-1}} I_{t-1} - d_1)$, the adjustment factor be $R^{*_{t-1}} + R^{*_{T-1}}$, the dollar is purchased from period 1 to $t=1$ to $t=T$, risk-adjusted intervention profits are
\[
\pi = \sum_{t=2}^{T} R^{*_{t}} CI_{t-1}. \]
Note that the measure in (2) combines profits from asset picking and from timing. As argued above, timing is the relevant source of profits or losses that the BOZ may make. Thus, we need to correct the measure in (2) to remove profits from asset picking.

A Correction to Find Profits from Timing. To adjust profits $\pi$ to find profits from timing ability, subtract from (2) the profits the BOZ would make if its actual exposure in every period were its average exposure $CI$. If the BOZ simply had this average exposure and made no trades, its profits would be $R^{*_{t}} CI$ in period $t$. This is the return to asset picking. Intuitively, if $CI > 0$ and $R^{*_{t}} > 0$ for $2 \leq t \leq T$, then gross profits are expected to be positive, ceteris paribus. Let the adjustment factor be $R^{*_{t}} CI$ in period $t$ and let the adjustment factor across the $(T-1)$ periods be $CI (R^{*_{2}} + R^{*_{3}} + \ldots + R^{*_{T}})$. Profits from timing, are then

\[ R^{*_{t}} = R_{t} - rp_{t-1} = (\Delta s_{t} - rp_{t-1}) + (i_{USD,t-1} - i_{ZMK,t-1}), \]
where the risk premium in $\Delta s_{t}$, lagged because the risk premium is an ex ante variable relative to $\Delta s_{t}$. The total amount exposed at the start of period $t$ is the cumulated purchased of USD outstanding at the end of period $t-1$ starting from period 1, or $CI_{1} = \sum_{j=1}^{3} I_{j}$, where $I_{j}$ is the amount of intervention in period $j$, purchases of USD, $CI$ is cumulative intervention in period $t$, and $CI_{0}$. The abnormal revenue in period $t$ from intervention is thus $R^{*_{t}} CI_{t}$. Over a given period, from $t=1$ to $t=T$, risk-adjusted intervention profits are

\[ \pi = \sum_{t=2}^{T} R^{*_{t}} CI_{t-1}. \]

---

2 The definition of intervention may be either BOZ purchases or sales of USD; it is natural in the text's development in this section to define intervention as purchases.

3 Suppose the BOZ buys $1 by selling ZMK X x 1/S in the foreign exchange market; for example, if the current exchange rate is $S_{t} = ZMK 1000/USD$, the government pays $X = ZMK 1000$ for USD 1. In the next period it makes gross profit on this decision if the risk-adjusted excess appreciation of the dollar is positive, where appreciation of the dollar is $\Delta s_{t-1} = \ln(S_{t-1} / S_{t})$ in continuously compounded terms. For the first-period dollar purchase $I_{0}$ the continuously compound return over $T$ periods is $I_{0} (R^{*_{2}} + R^{*_{3}} + \ldots + R^{*_{T}})$, for the second-period dollar purchase $I_{2} (R^{*_{2}} + R^{*_{3}} + \ldots + R^{*_{T}})$, and for the $T-1$-period dollar purchase $I_{T-1} (R^{*_{T}})$.

The sum of gross profits is
\[
I_{0} (R^{*_{2}} + R^{*_{3}} + \ldots + R^{*_{T}}) + I_{2} (R^{*_{2}} + R^{*_{3}} + \ldots + R^{*_{T}}) + \ldots + I_{T-1} (R^{*_{T}})
= (I_{0} + I_{2} + \ldots + I_{T-1}) R^{*_{2}} + (I_{0} + I_{2} + \ldots + I_{T-2}) R^{*_{3}} + \ldots + (I_{0}) R^{*_{T}}
= (CI_{T-1}) R^{*_{2}} + (CI_{T-2}) R^{*_{3}} + \ldots + (I_{0}) R^{*_{T}}
= \sum_{t=2}^{T} R^{*_{t}} CI_{t-1},
\]
where $CI_{t} = \sum_{j=1}^{t} I_{j}$ is cumulative purchases of USD from time 1 to $t$.

4 For the 1996-2009 sample period, the kwacha on average depreciated relative to the dollar, or the number of kwacha per dollar rose, that is, dollar appreciation was positive. Supposing that $R_{t} = \Delta s_{t}$ then $R > 0$. $CI$, however, was negative on average over the sample period, because on average the BOZ sold dollars rather than buying them,
R* is the mean risk-adjusted rate of return, \( \text{cov}(.) \) is the covariance operator, and (3) holds because \( \Sigma^T_{t=2} R^* (\text{CI}_{t-1} - \text{CI}) = 0 \). Intuitively, timing profits are positive if, on average, cumulative intervention is above average when the risk-adjusted rate of return is above average, or (\( \text{CI}_{t,1} - \text{CI} > 0 \)) on average when (\( R^* - R^* > 0 \)).

**Comparison with Previous Measures of Risk-Adjusted Profits.** Sweeney (1997, 2000) and Sjö and Sweeney (2000, 2001) develop their measures in a similar way, but with a crucial difference. They start with the excess return on holdings of foreign currency in period \( t \), measured from the BOZ point of view,

\[
R_t = \Delta s_t + (i_{USD,t-1} - i_{ZMK,t-1}).
\]

This measure is only a pseudo profit rate because it is not adjusted for risk. They form a measured of pseudo profits adjusted for current exposure as \( \Sigma^T_{t=2} R_t \text{CI}_{t-1} \). They then use the common technique of mean adjustment for risk, where they subtract from \( R_t \) its mean value \( R = (T-1)/(T-2) \Sigma^T_{t=2} R_t \) to give the mean-adjusted measure \( \Sigma^T_{t=2} (R_t - R) \text{CI}_{t-1} = \Sigma^T_{t=2} (R_t - R) (\text{CI}_{t-1} - \text{CI}) \) from \( \Sigma^T_{t=2} (R_t - R) \text{CI} = 0 \). This paper's measure and the previous measure are related as follows.

\[
\Sigma^T_{t=2} (R_t - R) (\text{CI}_{t-1} - \text{CI}) = \Sigma^T_{t=2} [(R_t - R) - (R - R)] (\text{CI}_{t-1} - \text{CI}) = \Sigma^T_{t=2} (R^* - R^*) (\text{CI}_{t-1} - \text{CI}).
\]

**Regression Model to Find Profits.** An alternative way to estimate profits is to calculate the OLS slope in a regression based on the model,

\[
(4) \quad R^* = a + b \text{CI}_{t-1} + u_t,
\]

where \( u_t \) is an error and \( a, b \) are parameters to be fit. Define \( R^*_{p,t} \) as the part of \( R^* \), purged of the explained portion from (4), or

\[
(5) \quad R^*_{p,t} = R^* - \hat{a} = \hat{b} \text{CI}_{t-1} + z_t,
\]

where \( z_t \) is a residual. Define purged profits from BOZ timing as

\[
(6) \quad \pi^\text{p}\text{im} = \Sigma^T_{t=2} R^*_{p,t} (\text{CI}_{t-1} - \text{CI}) = \Sigma^T_{t=2} (R^*_{p,t} - R^*_{p})(\text{CI}_{t-1} - \text{CI})
\]

or \( I_1 < 0 \) on average. Thus, \( \Delta s \text{CI} < 0 \)—the BOZ expected on average to lose money by its intervention. Suppose the BOZ loses less than \( \Delta s \text{CI} \), or \( 0 > \Delta s \text{CI} < \Sigma^T_{t=2} R_t \text{CI}_{t,1} < 0 \). Then, \( \pi > 0 \): Though the BOZ lost money, for example, because it was forced to sell aid funds to support the government, it used its insight into the market to lose less than otherwise. In the sense of losing less than expected, the BOZ beats the market. Note the further development in the text of risk-adjusted rates of return. In efficient markets, the expected risk-adjusted excess rate of return is zero, \( E_{\text{CI}}R^* = 0 \). Conditional on \( \text{CI} \), the expected value of \( R^* \) \( \text{CI} \) is zero, \( E_0 R^* \) \( \text{CI} \).
\[ = \Sigma_{t=2}^{T} (\hat{\delta} \text{CI}_t + z_t - \delta \text{Cl}) \text{ (CI}_{t-1} - \text{Cl}) \]
\[ = \Sigma_{t=2}^{T} \hat{\delta} \text{ (CI}_t - \text{Cl}) \text{ (CI}_{t-1} - \text{Cl}) + \Sigma_{t=2}^{T} z_t \text{ (CI}_{t-1} - \text{Cl}) = \Sigma_{t=2}^{T} \hat{\delta} \text{ (CI}_t - \text{Cl})^2 \]
\[ = \hat{\delta} (T-1) \text{var(CI)} , \]
where \( \text{sgn}(\eta_\text{lim}) = \text{sgn}(\hat{\delta}) \), \( \Sigma_{t=2}^{T} z_t \text{ (CI}_{t-1} - \text{Cl}) = 0 \) from OLS, and \( \text{var(CI)} \) is the sample variance of CI. Note that the regression approach gives an estimate of the standard error of \( \hat{\delta} \), allowing calculation of the t-statistic and hence the significance of \( \hat{\delta} \).

**Extension: What if Risk Premiums and Risk-Factor Realizations Are Not Available?** In (4), the dependent variable is \( R^*_t = R_t - \text{rp}_{t-1} = (\Delta s_t - \text{rp}_{t-1}) + (i_{\text{usd},t-1} - i_{\text{zmk},t-1}) \), and thus estimates of risk premiums \( \text{rp}_t \) are needed. If \( \text{rp}_t \) is time constant, then omitting it makes no difference in \( \text{cov}(R_t, \text{Cl}_{t-1}) \), as seen above. The risk premium \( \text{rp}_t \) is likely to vary over time, however. Ideally, one would like to use estimates \( \text{rp}_{t} \) of \( \text{rp}_t \) found from a multi-factor asset pricing model. Standard techniques, however, give \( \text{rp}_{t} \) only for the average of a long sample period. For a \( K \)-factor model, the risk premium in \( \Delta s_t \) is \( \text{rp}_{t-1} = \Sigma_{k=1}^{K} \beta_{k,s,t} \text{rp}_{k,t-1} \), where \( \text{rp}_{k,t} \) is the time-varying risk premium on the economy-wide risk factor \( k \), there are \( K \) priced risk factors, and \( \beta_{k,s,t} \) is the beta of \( \Delta s \) on the \( k^{th} \) risk factor in \( t \).

Such estimation has two difficulties for many countries, including Zambia. First, one might use industrialized-country asset-pricing factors, such as Fama-French factors, which gives timing issues; Zambia is six hours earlier than New York. (These timing problems apply just as strongly to western European countries, which are five to seven hours earlier than New York.) Second, Zambia may not be fully integrated with world financial markets: thus, some factors peculiar to Zambia may be priced there, and industrialized-country factors may not be priced.

5 Further, the error term in (4) can be decomposed into
\[ u_t = \Sigma_{k=1}^{K} \beta_{k,s,t} \delta_{k,t} + w_t \]
where \( \delta_{k,t} \) is the beta of \( \Delta s \) on the \( k^{th} \) risk factor in \( t \), \( w_t \) is an idiosyncratic error. In this framework, \( \text{rp}_{t} = \Sigma_{k=1}^{K} \beta_{k,s,t} \text{rp}_{k,t} \), where \( \text{rp}_{k,t} \) is the time varying risk premium on factor \( k \). It is common in work on exchange rates to use an error such as \( u_t \) rather than to attempt to decompose it to find the effects of risk-factor realizations.

6 Consider the Fama-MacBeth approach, widely used for 40 years. In the first pass equations,
\[ R_{jt} - r_{jt} = \alpha_j + \Sigma_{k=1}^{K} \beta_{j,k} \delta_{k,t} + \epsilon_{j,t} \]
where the rate of return \( R_{jt} \) on the jth portfolio in period \( t \), the risk-free rate \( r_{jt} \) in period \( t \), the economy wide risk-factor realization \( \delta_{k,t} \) on the kth risk factor in period \( t \) are all observable, and the parameters \( \alpha_j \) and \( \beta_{j,k} \) and the error \( \epsilon_{j,t} \) are estimated across the N portfolios \( (j=1,N) \) and the estimation periods contains \( \tau \) periods. If the total number of observations is \( T \) and rolling regressions are used, this gives \( T-\tau \) estimates.

7 For the Fama/French risk-factor realizations, see
there or may have different risk premiums if priced. High quality data are not available for finding such non-standard factors. This paper cuts this knot by assuming that any variable that helps explain depreciation $\Delta s_t$ is a predictor of the time-varying risk premium in $\Delta s_t$. Subtracting from $\Delta s_t$ the part that is explainable is taken as given the risk-adjusted appreciation rate. The alternative approach used here adds the predictors of $\Delta s_t$ to equation (4) above, thereby removing their effects from the estimate of the slope on $CI_{t-1}$. This suggests that an equation of the form

\[ \Delta s_t = a_0 + a_1 CI_{t-1} + a_{21} I_{t-1} + a_{22} I_{t-2} + \ldots + a_{31} \Delta s_{t-1} + a_{32} \Delta s_{t-2} + \ldots + \sum_{h=1}^{2009} a_{dh} d_h + \sum_{j=1}^{10} a_{1j} D_j + \ldots + u_t, \]

lagged interventions are instruments, as are lagged depreciation rates and fixed-time effects (year dummies, $d_h$). The equation also includes ten $\Delta s_t$-outlier dummies ($D_j$) to correct any biases that may arise from outliers detected before estimation. From

\[ \pi_p^{\text{im}} = \hat{\alpha}_1 (T-1) \text{var}(CI), \]

\[ \text{sgn}(\pi_p^{\text{im}}) = \text{sgn}(\hat{\alpha}_1). \hat{\alpha}_1 > 0 \text{ implies that the BOZ makes profits from its intervention. Again, the t-value of } \hat{\alpha}_1 \text{ gives a statistical test of the significance of measured profits.} \]

**Extension: The Interest Rate Differential.** The interest rate differential, $(i_{\text{usd},t-1} - i_{\text{zmk},t-1})$, can be quite large, especially because Zambia had important inflation during the sample period. Unfortunately, there is not a good series available for $i_{\text{zmk},t}$ and the work below necessarily omits $(i_{\text{usd},t-1} - i_{\text{zmk},t-1})$. Similar to the case with the risk premium, if $(i_{\text{usd},t-1} - i_{\text{zmk},t-1})$ is time constant, then omitting it has no effect on measured intervention profits. In fact, the differential varies over time. Data from a variety of countries show that the variance of differentials is small relative to the variance of appreciation rates (Sweeney 1997, 2000, 2007), making the omission less important than otherwise. If the omitted differential is important in explaining $\Delta s_t$, then the estimate $\pi_p^{\text{im}}$ from (7) is (a) adjusted for the omission to the extent the included variables pick up the differential, (b) biased upwards (downwards) if the covariance of the unpurged portion of the differential with cumulative intervention is positive (negative), but (c) the remaining bias is small because the variance of $(i_{\text{usd},t-1} - i_{\text{zmk},t-1})$ is small. This discussion suggests that in the absence of data appropriate for forming $(i_{\text{usd},t-1} - i_{\text{zmk},t-1})$, the analyst may use equation (7).

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8 In the estimated equations reported below, insignificant fixed-time effects are omitted. If all were included, the equations would have to omit the intercept term.

9 In experiments, omitting the outlier dummies affects parameter estimates and gives significant outliers in the residuals.
**Relationship to Uncovered Interest Parity.** A related consideration is the relationship between \((i_{usd,t} - i_{zmk,t})\) and \(r_p\) to the unbiasedness hypothesis (UH). Under the UH, \(E \Delta s_{t+1} = (i_{zmk,t} - i_{usd,t})\) or \(E \Delta s_{t+1} + (i_{usd,t} - i_{zmk,t}) = 0\). Most empirical test strongly reject the null that the UH holds. Researchers offer various explanations, some arguing that data problems are responsible for the failure of UH to hold. Another major explanation is that \(E \Delta s_{t+1} + (i_{usd,t} - i_{zmk,t})\) depends on a risk premium and \(E \Delta s_{t+1} + (i_{usd,t} - i_{zmk,t}) = r_p\). Using equation (7) allows for the possibility that the instruments explain \((i_{usd,t} - i_{zmk,t}) - r_p\) and thus allows for the possibility that \(E \Delta s_{t+1} + (i_{usd,t} - i_{zmk,t}) - r_p = 0\) and \(a_1 = 0\) (because the lagged values of intervention, depreciation, and the dummies capture the effects of \(r_p\)).

**Simultaneous Equations Bias.** Estimating an equation based on (7) leaves open the possibility of simultaneous equations bias, because the central bank’s reaction function (or intervention function) may relate intervention to depreciation, for example,

(9) \[
I_t = b_0 + b_1 \Delta s_t + b_{21} I_{t-1} + b_{22} I_{t-2} + \ldots + b_{31} \Delta s_{t-1} + b_{32} \Delta s_{t-2} + \ldots + \sum_{h=1996}^{2009} b_{dh} d_h + \sum_{j=1}^{10} b_{dj} D_j + \ldots + v_t.
\]

It might appear that simultaneous equations bias is not a problem because the intervention variable in (7) is the stock variable cumulative intervention, \(CI_{t-1}\), but the intervention variable in (9) is flow intervention, \(I_t\). Nevertheless, as the next section discusses, in an OLS regression of \(I_t\) on \(CI_{t-1}\), the slope of \(CI_{t-1}\) is significant at conventional levels. To avoid simultaneous equations bias, the estimated model is the simultaneous system (7) and (9). The estimation uses SUR techniques to take account of cross correlation in the errors \(u_t\) and \(v_t\) in (7) and (9).

### 5. Empirical Results

The sample period 1996-2009 breaks naturally into two sub-periods. The first sub-period, 1996-2002, was a period of copper-market bust. Copper prices were low and export demand was weak. The second sub-period, 2003-2009, was largely a period of copper boom, with substantially higher copper prices and stronger export demand, but a sharp break in prices in 2008 with a quick rebound.

Tables 1-3 show SUR estimation results from the whole sample period, 1996-2009, and the two sub-periods. The estimated slope coefficients on \(CI_t\) are all positive, and are significant at the 0.0459, 0.3267 and 0.0698 levels. These coefficients are small, on the order of \(10^{-6}\); this might be expected because these are weekly data and use \(CI_t\) rather than \(I_t\).
**Estimates of Profits from Intervention.** The figures below, found from (8), show estimated profits from the whole period, the two sub-periods, and the sum of the estimated profits from the two sub-periods:

<table>
<thead>
<tr>
<th>Years</th>
<th>Profits</th>
<th>t-value</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-2009</td>
<td>$257.1916m</td>
<td>1.998285</td>
<td>0.0459**</td>
</tr>
<tr>
<td>1996-2002</td>
<td>$18.9598m</td>
<td>0.981409</td>
<td>0.3267</td>
</tr>
<tr>
<td>2003-2009</td>
<td>$40.2422m</td>
<td>1.814793</td>
<td>0.0698*</td>
</tr>
</tbody>
</table>

Note four remarks regarding these estimated profits. First, profits are positive in each period from $\hat{a}_1 > 0$. Second, $\hat{a}_1$ and thus profits are significant at the 0.0459, 0.3267 and 0.0698 levels. Third, profits are larger in the whole-period estimate than the sum of the two sub-period's profits, $257.1916m$ versus $59.2020m$. This follows because var($\text{CI}_t$) is larger for the whole period than for that of either sub-period (44,050 versus 6,368 or 17,882, as Figure 1 suggests) and $\hat{a}_1$ for the whole period ($8.27 \times 10^{-6}$) is approximately the same as for the first sub-period ($8.63 \times 10^{-6}$) but over a third larger than for the second sub-period ($6.20 \times 10^{-6}$). Fourth, the entry for sum of sub-period profits in the t-value column is the sum of the squared t-values times 2 (or $2.063162 \times 2 = 4.126324$); under the null that the mean profit is zero and that the sum of profits are independent across periods, this value is distributed as $\chi^2(1)$. Intuitively, if the expected t-value is zero, the probability of finding two out of two consecutive values significant at the 0.3267 and 0.0698 levels or better occurring by chance is only 4% under the null.

**Profits from Timing and Profits from Asset Picking.** The two estimates of profits from timing for the whole period are $257.1916m and $59.2020m. Turn to the profits from asset picking. The average cumulative intervention is -$324.4651m (the maximum is -880.1449, the minimum is -14.10). The mean purged rate of return is 8.54 $10^{-19}$ and thus the average cumulative intervention times the mean purged rate of return is very close to zero (-2.7799 $10^{16}$ = -$324.4651 \times 8.54 \times 10^{-19}$). Thus, the total profits from asset picking plus timing is essentially that from timing.

Using the larger estimate of risk-adjusted profits, the BOZ made $257.1916m on a base of $324.4651m, or over a period of 13 and a half year made a profit rate of $257.1916m / $324.4651m = 0.792663 or 79.2663% or 5.8716%/yr, $19.0512m/yr. Note that the risk-adjusted profits in rates or dollars are only 23.02% of these if the analyst uses the estimate $59.2020m.
**SUR Results Compared to OLS Results.** Table 4 shows estimates obtained from OLS of the same specification for the equation explaining kwacha depreciation for the whole period in Table 1. The difference is that results in Table 1 are from a simultaneous system estimated with SUR and those in Table 4 are from single-equation estimation with OLS. The analyst may interpret the difference in estimates as arising from simultaneous equations bias in the OLS estimates. The key estimates are of $a_1$. From Tables 1 and 4, the estimates are $8.27 \times 10^{-6}$ and $8.24 \times 10^{-6}$, a difference of $0.3641\%$ relative to the lower slope estimate. Similarly, estimated profits from OLS are smaller by $0.3641\%$,\(^{10}\) wholly owing to differences in the slopes. In this case, the simultaneous equations bias is trivial. On the one hand, this example shows that results from OLS approaches need not be far in error. On the other hand, the researcher cannot be sure that differences in other cases will not be orders of magnitudes greater.

**Transactions Costs: Size and Effects on Estimated Profits.** One on-line bid-ask spread on May 9, 2014 was $2.99063\% \approx 3\%$.\(^{11}\) Of course, this spread is surely an underestimate for the early years in the sample period, and perhaps for much of the sample period. One approach is to compare the estimated profits to the total absolute value of intervention. The total absolute value of intervention over 1996-2009 is $1,998.67m$. The larger estimate of profits is $257.1916m$, a rate of $12.8868\%$. For transaction costs to exhaust estimated profits, the spread would have to be twice this percentage, or $25.7736\%$. This is wholly implausible. If one uses the lower estimate, however, the implied spread that exhausts the estimated profits is $5.9331\%$. This is smaller but still appears implausible.

It is not clear, however, that transaction costs should be charged against BOZ intervention profits. The BOZ is not independent and does not have full control over its intervention policies. The GOZ, however, wants the BOZ to stabilize fluctuations in the exchange rate. This allows the BOZ some discretion in the timing of transactions that it would have to make in any case, either to convert aid received in dollars to kwacha or to buy dollars to fight appreciation of the kwacha. If the BOZ would have to have made the transactions in total anyway, the opportunity cost chargeable to BOZ profits is zero.

6. Is Cumulative Intervention Non-stationary and Integrated?

\(^{10}\) From OLS, estimated profits are $256.2582m$.

\(^{11}\) The bid and ask were 5,079.00 and 5,233.20. The spread is then 154.20, and the spread relative to the average of the bid and ask is 0.299063. See [http://www.investing.com/currencies/usd-zmk](http://www.investing.com/currencies/usd-zmk).
One possible objection to the tests is that \((7)\) may be “unbalanced,” because profits \(R_t\) are stationary while cumulative intervention (CI_t) is non-stationary and integrated or near-integrated. In Phillips-Perron tests on weekly intervention data, the series for cumulative intervention cannot reject the unit-root null.\(^{12}\) Further, weekly data cannot reject the unit-root null for the log exchange rate but can reject the null for the change in the log exchange rate. These results suggest that equations for the profit function \((7)\) in Tables 1-3 might be misspecified. If CI_t ∼ I(1) but Δs_t ∼ I(0), then the profit function equations are unbalanced—an integrated variable cannot explain a stationary variable and in the true equation corresponding to \((6)\) the slope on CI_t must be zero. The appendix below, based on Sjö and Sweeney (2009), shows that under the null that the explanatory variable CI_t ∼ I(1), if the appropriate number of leads and lags of intervention (I_t = Δ CI_t) is included in the regression, then the t-value of the coefficient of CI_t is distributed N(0, 1) around a slope of zero. They suggest using a number of leads and lags approximately equal to \(T^{1/4}\), giving \(T^{14} = 708^{1/4} = 5.15\). The null is that CI_t ∼ I(1) [and thus the true slope in zero]; the alternative is that CI_t ∼ I(0) and the slope is non-zero. Table 6 shows that with five leads and lags, the coefficient on CI_t is 1.28 \(10^{-5}\) with a t-value of 2.972399 (probability: 0.31%)—the data strongly reject the null that CI_t ∼ I(1).\(^{13}\) Intuitively, it is well known that conventional unit-root tests are not powerful if the true root is close to unity. The test used here is more powerful, because it is more highly structured by taking into account the fact that Δs_t and CI_{t−1} are related—the correlation of I_t and Δs_t is 0.132890. Thus, from the results in Table 6, it is legitimate to run this paper’s SUR systems: Profit-function equations are not unbalanced.

**How Reliable Is the Size of the Test?** Since at least Mankiw and Shapiro (1986), it is well known that the actual size of a test may be larger, even quite a bit larger, than the nominal size, if the regressor as in \((7)\) is stationary but has a large root. The size bias depends positively on (i) the root of the regressor and (ii) the correlation between the errors in \((7)\) and \((9)\), but depends negatively on the number of observations. Sjö and Sweeney (2009) show that asymptotically the bias in the estimate of the slope of CI_t is \(ρ_{1,2t} (1 - κ)\), where \(ε_{1t}\) and \(ε_{2t}\) are the errors in the true equations to which \((7)\) and \((9)\) correspond and \(κ ≤ 1\) is the maximal root in CI_t. Suppose \(κ\) is 0.90

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12 Because CI_t is not a smooth series one can argue that tests for the order of integration might be misleading. It is sufficient for a series to be near-integrated to cause problems with inference. This is so because the distribution of the test statistics is better approximated by that of an integrated variable than the distribution of a stationary variable.

13 In another experiment, including the outlier dummies D1 and D2 and year dummies d_{2001}, d_{20005}, d_{2007}, the slope is -1.32 \(10^{-5}\) and t-value -2.845330 (probability: 0.0046).
or even 0.99. From (7) and (9), the estimated correlation between the equations' errors is -0.005228. Then, the asymptotic bias is $-0.005228 \times 0.10 = -5.23 \times 10^{-5}$ for $\kappa = 0.90$ and $-5.23 \times 10^{-4}$ for $\kappa = 0.99$. The size of the test is at most very slightly biased downward, that is, against the positive estimated profits.

7. Summary and Conclusions

The surprising result reported here is that Zambia's central bank made economically and statistically significant profits from intervention; these profits are risk adjusted by using the proxy variable approach this paper develops. Over the sample period 1996-2009, risk-adjusted profits are economically and statistically significant at $5.8716\%/yr$ or $19.0512$m/yr in the higher estimate and $1.3516\%/yr$ or $4.3853$m/yr in the lower estimate. Profits were also economically and statistically significant in the second-half sample period, 2003-2009; in the first-half sample period, 1996-2002, profits were economically but not statistically significant.

Our estimated profits have weaknesses. Good data for interest rate differentials are not available and this paper thus omits them in estimates. Similarly, because of timing issues and lack of data, the paper omits direct estimates of risk premiums. Instead, this paper uses a proxy variable approach: we assume that pre-determined variables that predict the coming depreciation rate are picking up the omitted risk premiums and interest rate differentials. It is not possible to know if this approach is adequate until appropriate data are available.

Furthermore, adequate data are not available for correctly estimating the bid-ask spreads that the BOZ would have to pay and thus the total transaction costs that should be netted from estimated profits. On the one hand, the spread would have to be almost 6% to exhaust the lower estimate of profits or over 25% to exhaust the higher estimate of profits. On the other hand, if the BOZ would have had to make equivalent transactions anyway and simply chose the timing of transactions in hope of profits, the opportunity costs of making the actual transactions would be zero.

Zambia is of interest as representative of a variety of developing countries. Zambia is representative of sub-Saharan African countries, of low-income countries, and of aid-recipient countries. Further, copper is a major part of Zambia's exports; Zambia thus represents the many developing countries dependent on natural-resource exports and more generally dependent on staple exports. At first glance, these might not seem the types of countries likely to profit from
intervention as compared to the most sophisticated industrialized countries. This perspective may not be fair. Neglecting transaction costs, in an efficient market the BOZ should expect to make zero risk-adjusted profits from its timing strategy. Some observers point out that central banks have inside information on monetary and intervention policy and may be able to exploit this information to profit. Yet others are skeptical of central bank competence and predict losses rather than profits. The issue is then empirical, and this paper provides the first answer of developing countries: Zambia appears to make profits from its intervention.
Appendix: Efficiency Test Regression

The data generating process is

(A.1) \[ y_t = \beta x_{t-1} + \varepsilon_{1t}, \]

(A.2) \[ x_t = \kappa x_{t-1} + \varepsilon_{2t}, \quad \kappa \leq 1, \]

where \( y_t \) is the asset’s rate of return, \( x_t = \sum_{j=1}^{t} \Delta x_j + x_0 \), \( \varepsilon_{1t} = \{ \varepsilon_{1t}, \varepsilon_{2t} \} - \text{iid N}(0, \Theta), \)

\[ \Theta = \begin{bmatrix} \theta_{11} & \theta_{12} \\ \theta_{21} & \theta_{22} \end{bmatrix} \]

where the ‘\(^{\prime}\)’ indicates contemporaneous covariances. Their long-run covariance matrix \( \Sigma \) is

\[ \Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix} = \Sigma + \Gamma + \Gamma' \]

where

\[ \Gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix} = \left[ \sum_{k=1}^{\infty} E(\varepsilon_{1t} \varepsilon_{1t-k}) , \sum_{k=1}^{\infty} E(\varepsilon_{1t} \varepsilon_{2t-k}) \right] \]

Under the null, \( \beta = 0 \) in the true equation (A.1). Note from (A.2), \( \Delta x_t = (\kappa - 1) x_{t-1} + \varepsilon_{2t}, \kappa \leq 1. \)

Note further that the analyst can orthogonalize \( \varepsilon_{1t} \) relative to \( \varepsilon_{2t} \) as

\[ \varepsilon_{1t} = \mu + \varepsilon_{1t} + e_t, \quad \mu = \theta_{12}/\theta_{22}, \quad E \varepsilon_{2t} e_{t-j} = 0 = E x_t e_{t-j} \text{ for all } t, j. \]

Consider two efficiency-test regressions.

**Standard efficiency-test regression**

(A.3) \[ y_t = \delta_0 + \delta_1 x_{t-1} + z_t, \quad t = 1, \ldots, T. \]

Theorem 1: \( x_t \sim I(1) [\kappa = 1]. \) In the efficiency-test regression (A.3): If \( \sigma_{12} = 0 \), then \( t_1 \rightarrow N(0, 1) \) as \( T \rightarrow \infty; \) if \( \sigma_{12} \neq 0 \), then \( t_1 \) does not go to a \( N(0, 1) \) variate as \( T \rightarrow \infty. \)

Theorem 2: \( x_t \sim I(0) [k < 1]. \) If \( \sigma_{12} = 0 \) or \( \sigma_{21} \neq 0 \), then under the null \( t_1 \rightarrow N(0, 1) \) as \( T \rightarrow \infty. \)

**Sketch of proofs of Theorems 1 and 2:** To understand how the cross-correlation between \( \varepsilon_{1t} \) and \( \varepsilon_{2t} \) affects the distribution of \( \delta_1 \), consider their long-run covariance matrix \( \Sigma. \) If \( x_t \) is highly persistent, the skewed distribution of \( \delta_1 \) follows from any non-zero off-diagonal elements in \( \Sigma, \) i.e., \( \sigma_{12} = \omega_{12} + 2 \gamma_{12} \neq 0 \) or \( \sigma_{21} = \omega_{21} + 2 \gamma_{21} \neq 0. \)

Consider what the sums in the OLS estimate of \( \delta_1 \) converge to asymptotically in the limiting case of \( x_t \sim I(1). \) The stochastic properties come \( \varepsilon_{1t} \) and \( \varepsilon_{2t}. \) Under quite general assumptions, the cumulated sums of \( \varepsilon_{1t} \) and \( \varepsilon_{2t} \) asymptotically converge to functionals of Brownian motions as \( T \rightarrow \infty. \) Let \( B = [B_1(r), B_2(r)]' \) represent the bivariate Brownian motion \( BM(\Sigma), \) with the long-run
covariance matrix $\Sigma$ as above. If $\kappa = 1$, then in the OLS estimate $\hat{a}_1$, the denominator converges in distribution to a functional of a Brownian motion,

$$T^{-2} \Sigma_{t=1}^T (x_{t-1} - x)^2 \rightarrow^d \sigma_{22} \int [B_2(r) - \int B_2(s) ds]^2 \, dr$$

and the numerator converges to

$$T^{-1} \sum_{t=1}^T (x_{t-1} - x) z_t \rightarrow^d \sigma_{12} \int [B_2(r) - \int B_2(s) ds] dB_{1.2} \, dr + \gamma_{12},$$

where $B_{1.2}$ represents the outcome of conditioning $B_1$ on $B_2$, the residual in (A.3). The parameter $\gamma_{12}$ is a potential bias in $\hat{a}_1$ arising from correlations between $y_t$ and lagged values of $\epsilon_{2t}$. The latter is of particular interest in an EMH regression because it implies predictability from $\epsilon_{2t-k}$ on $y_t$ for $k > 0$ and hence a rejection of efficiency.

Phillips (1987) shows that $\sigma_{22} \int [B_2(r) - \int B_2(s) ds] dB_{1.2} \, dr$ has an asymptotic normal distribution conditional on $\Sigma_{t=1}^T (x_{t-1} - x)^2$ only if $B_{1.2}$ and $B_2$ are independent. In all other cases, i.e., with non-zero off-diagonal elements in $\Sigma$, the distribution of $\hat{a}_1$ is skewed. Consequently, a significance test based on the assumption of asymptotic normality can only reject the null of independence between $y_t$ and $x_t$; in particular, rejection of the null does not imply that $\hat{a}_1$ is significant and that the market is inefficient.

**Modified efficiency-test regression:** Include the change $\Delta x_t$

(A.4) \hspace{1cm} \begin{align*} y_t &= \hat{a}_0 + \hat{a}_1 x_{t-1} + \hat{a}_2 \Delta x_t + u_t, \quad t = 1, \ldots, T. \end{align*}

**Theorem 3:** $x_t \sim I(1)$ [$\kappa = 1$]. Under the null, in (A.4) $t_{a1} \sim N(0, 1)$ for $T \geq 30$.

**Theorem 4:** $x_t \sim I(0)$ [$\kappa < 1$]. Under the null, $t_1$ does not go to a $N(0, 1)$ variate even as $T \rightarrow \infty$.

Instead, as $T \rightarrow \infty$, then $\hat{a}_1 \rightarrow \mu (1 - \kappa)$.

**Proof.** Substitute into (A.1) from (A.2) for $\epsilon_{2t}$ to give

(A.1"") \hspace{1cm} \begin{align*} y_t &= \beta x_{t-1} + \mu [\Delta x_t + (1 - \kappa) x_{t-1}] + \epsilon_t = [\beta + \mu (1 - \kappa)] x_{t-1} + \mu \Delta x_{t-1} + \epsilon_t. \end{align*}

If $\beta = 0$ and $\kappa = 1$, then the true slope of $x_{t-1}$ is zero, and from $\epsilon_t$ orthogonal to $x_{t-1}$, $t_{a1} \sim N(0, 1)$ for $T \geq 30$. If $\kappa < 1$, then under the null, the slope on $x_{t-1}$ is $\mu (1 - \kappa)$, and the OLS estimate $\hat{a}_1$ is biased by $\mu (1 - \kappa)$. For $T \geq 30$, the $t$-value around $\mu (1 - \kappa)$ is distributed $N(0, 1)$, and hence the $t$-value around zero, $t_{a1}$, is not standard normal.
References


Notes: The cumulative intervention variable is purchases of USD. The price of copper is USD per ton. The exchange rate $S$ is the number of kwacha per USD. The data are normalized (demeaned and relative to standard deviation).
Table 1. Seemingly Unrelated Regression: 1996-2009

\[ \Delta \ln S_t = a_0 + a_1 C_{t-1} + a_{21} D_1 + a_{22} D_2 + a_{35} d_{2005} + u_t \]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0$</td>
<td>0.005509</td>
<td>0.001529</td>
<td>3.603530</td>
</tr>
<tr>
<td>$a_1$</td>
<td>8.27E-06</td>
<td>4.14E-06</td>
<td>1.998285</td>
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<tr>
<td>$a_{21}$</td>
<td>-0.148356</td>
<td>0.021840</td>
<td>-6.792911</td>
</tr>
<tr>
<td>$a_{22}$</td>
<td>-0.102300</td>
<td>0.021839</td>
<td>-4.684326</td>
</tr>
<tr>
<td>$a_{35}$</td>
<td>-0.008164</td>
<td>0.003305</td>
<td>-2.470238</td>
</tr>
</tbody>
</table>

R-squared: 0.101978
Adjusted R-squared: 0.096861
Mean dependent var: 0.001873
S.D. dependent var: 0.023031
Sum squared resid: 0.336304
Durbin-Watson stat: 2.144580

\[ I_t = b_0 + b_1 \Delta \ln S_t + b_{21} I_{t-1} + b_{32} d_{2002} + v_t \]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>-0.556752</td>
<td>0.221064</td>
<td>-2.518514</td>
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<tr>
<td>$b_1$</td>
<td>-24.23866</td>
<td>9.154367</td>
<td>-2.647770</td>
</tr>
<tr>
<td>$b_{21}$</td>
<td>0.390180</td>
<td>0.034499</td>
<td>11.30994</td>
</tr>
<tr>
<td>$b_{32}$</td>
<td>-1.564551</td>
<td>0.806967</td>
<td>-1.938804</td>
</tr>
</tbody>
</table>

R-squared: 0.177344
Adjusted R-squared: 0.173838
Mean dependent var: -1.202041
S.D. dependent var: 6.149032
Sum squared resid: 21991.32
Durbin-Watson stat: 2.112702

Cross-correlation of residuals: -0.005228
Table 2. Seemingly Unrelated Regression: 1996-2002

\[
\Delta \ln S_t = a_0 + a_1 C_{t-1} + a_{21} D_1 + a_{22} D_2 + a_{23} D_3
\]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a_0)</td>
<td>0.005948</td>
<td>0.001430</td>
<td>4.159950</td>
</tr>
<tr>
<td>(a_1)</td>
<td>8.63E-06</td>
<td>8.80E-06</td>
<td>0.981409</td>
</tr>
<tr>
<td>(a_{21})</td>
<td>-0.148149</td>
<td>0.012821</td>
<td>-11.55546</td>
</tr>
<tr>
<td>(a_{22})</td>
<td>-0.102239</td>
<td>0.012817</td>
<td>-7.976702</td>
</tr>
<tr>
<td>(a_{23})</td>
<td>-0.134091</td>
<td>0.012819</td>
<td>-10.46066</td>
</tr>
</tbody>
</table>

R-squared: 0.467432  Mean dependent var: 0.003607
Adjusted R-squared: 0.461166  S.D. dependent var: 0.017595
S.E. of regression: 0.012916  Sum squared resid: 0.056717
Durbin-Watson stat: 1.482751

\[
I_t = b_0 + b_1 \Delta \ln S_t + b_{21} I_{t-1} + b_{22} I_{t-2} + b_{32} d_{2002}
\]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b_0)</td>
<td>-0.480697</td>
<td>0.170953</td>
<td>-2.811871</td>
</tr>
<tr>
<td>(b_1)</td>
<td>10.12595</td>
<td>8.448568</td>
<td>1.198541</td>
</tr>
<tr>
<td>(b_{21})</td>
<td>0.115212</td>
<td>0.052593</td>
<td>2.190629</td>
</tr>
<tr>
<td>(b_{22})</td>
<td>0.179584</td>
<td>0.050830</td>
<td>3.533046</td>
</tr>
<tr>
<td>(b_{32})</td>
<td>-2.084891</td>
<td>0.450913</td>
<td>-4.623714</td>
</tr>
</tbody>
</table>

R-squared: 0.162452  Mean dependent var: -1.084696
Adjusted R-squared: 0.152599  S.D. dependent var: 3.021763
S.E. of regression: 2.781666  Sum squared resid: 2630.806
Durbin-Watson stat: 1.993096

Cross-correlation of residuals: -0.098098
### Table 3. Seemingly Unrelated Regression: 2003-2009

\[ \Delta \ln S_t = a_0 + a_1 \triangleleft CP_{t-1} + a_{24} D_4 + a_{25} D_5 + a_{26} D_6 + a_{27} D_7 + a_{28} D_8 + a_{29} D_9 + a_{31} D_{10} + a_{35} d_{2005} + a_{41} \Delta \ln S_{t-1} + a_{43} \Delta \ln S_{t-3} \]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0$</td>
<td>0.004155</td>
<td>3.281164</td>
<td>0.0011***</td>
</tr>
<tr>
<td>$a_1$</td>
<td>6.20E-06</td>
<td>1.814793</td>
<td>0.0698*</td>
</tr>
<tr>
<td>$a_{24}$</td>
<td>0.070938</td>
<td>3.950320</td>
<td>0.0001***</td>
</tr>
<tr>
<td>$a_{25}$</td>
<td>0.084787</td>
<td>4.702522</td>
<td>0.0000***</td>
</tr>
<tr>
<td>$a_{26}$</td>
<td>0.224197</td>
<td>11.87595</td>
<td>0.0000***</td>
</tr>
<tr>
<td>$a_{27}$</td>
<td>-0.106891</td>
<td>-5.933245</td>
<td>0.0000***</td>
</tr>
<tr>
<td>$a_{28}$</td>
<td>-0.190347</td>
<td>-10.51110</td>
<td>0.0000***</td>
</tr>
<tr>
<td>$a_{29}$</td>
<td>-0.190632</td>
<td>-10.65859</td>
<td>0.0000***</td>
</tr>
<tr>
<td>$a_{31}$</td>
<td>-0.068512</td>
<td>-3.813754</td>
<td>0.0001***</td>
</tr>
<tr>
<td>$a_{35}$</td>
<td>-0.004827</td>
<td>-1.759659</td>
<td>0.0787*</td>
</tr>
<tr>
<td>$a_{41}$</td>
<td>0.128000</td>
<td>4.030403</td>
<td>0.0001***</td>
</tr>
<tr>
<td>$a_{43}$</td>
<td>0.054590</td>
<td>1.830586</td>
<td>0.0674*</td>
</tr>
</tbody>
</table>

R-squared | 0.402543 | Mean dependent var | 0.001878 |
Adjusted R-squared | 0.393059 | S.D. dependent var | 0.023064 |
S.E. of regression | 0.017968 | Sum squared resid | 0.223741 |
Durbin-Watson stat | 1.821412 |

\[ I_t = b_0 + b_1 \Delta \ln S_t + b_{21} I_{t-1} + b_{22} I_{t-2} + b_{35} d_{2005} + b_{36} d_{2006} + b_{37} d_{2007} \]

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>-1.083571</td>
<td>-4.335068</td>
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</tr>
<tr>
<td>$b_1$</td>
<td>-17.00581</td>
<td>-1.880712</td>
<td>0.0602*</td>
</tr>
<tr>
<td>$b_{21}$</td>
<td>0.310195</td>
<td>8.273779</td>
<td>0.0000***</td>
</tr>
<tr>
<td>$b_{22}$</td>
<td>0.121401</td>
<td>3.253015</td>
<td>0.0012***</td>
</tr>
<tr>
<td>$b_{35}$</td>
<td>2.423202</td>
<td>2.959597</td>
<td>0.0031***</td>
</tr>
<tr>
<td>$b_{36}$</td>
<td>2.070084</td>
<td>2.544966</td>
<td>0.0110**</td>
</tr>
<tr>
<td>$b_{37}$</td>
<td>1.663444</td>
<td>2.067443</td>
<td>0.0389**</td>
</tr>
</tbody>
</table>

R-squared | 0.207019 | Mean dependent var | -1.193699 |
Adjusted R-squared | 0.200222 | S.D. dependent var | 6.149374 |
S.E. of regression | 5.499404 | Sum squared resid | 21170.41 |
Durbin-Watson stat | 2.022954 |

Cross-correlation of residuals: -0.106919
### Table 4. Ordinary Least Squares: 1996-2009

\[ \Delta \ln S_t = a_0 + a_1 C_{t-1} + a_{21} D_1 + a_{22} D_2 + a_{35} d_{2005} + u_t \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0$</td>
<td>0.005501</td>
<td>0.001534</td>
<td>3.585951</td>
<td>0.0004***</td>
</tr>
<tr>
<td>$a_1$</td>
<td>8.24E-06</td>
<td>4.15E-06</td>
<td>1.984189</td>
<td>0.0476**</td>
</tr>
<tr>
<td>$a_{21}$</td>
<td>-0.148321</td>
<td>0.021917</td>
<td>-6.767226</td>
<td>0.0000**</td>
</tr>
<tr>
<td>$a_{22}$</td>
<td>-0.102277</td>
<td>0.021916</td>
<td>-4.666668</td>
<td>0.0000**</td>
</tr>
<tr>
<td>$a_{35}$</td>
<td>-0.008194</td>
<td>0.003317</td>
<td>-2.470347</td>
<td>0.0137**</td>
</tr>
</tbody>
</table>

- **R-squared**: 0.101978
- **Adjusted R-squared**: 0.096861
- **S.E. of regression**: 0.021988
- **Sum squared resid**: 0.336304
- **Log likelihood**: 1701.357
- **Prob(F-statistic)**: 0.000000

- **Mean dependent var**: 0.001873
- **S.D. dependent var**: 0.023031
- **Akaike info criterion**: -4.798748
- **Schwarz criterion**: -4.766492
- **Hannan-Quinn criter.**: -4.786285
- **Durbin-Watson stat**: 2.144542
Table 5. Ordinary Least Squares, $I_t$ Regressed on $CI_{t-1}$: 1996-2009

\[ I_t = c_0 + c_1 CI_{t-1} + u_t \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_0$</td>
<td>0.313788</td>
<td>0.424639</td>
<td>0.738954</td>
<td>0.4602</td>
</tr>
<tr>
<td>$c_1$</td>
<td>0.002744</td>
<td>0.001102</td>
<td>2.489530</td>
<td>0.0130</td>
</tr>
</tbody>
</table>

R-squared: 0.008702  Mean dependent var: -1.202041
Adjusted R-squared: 0.007298  S.D. dependent var: 6.149032
S.E. of regression: 6.126552  Akaike info criterion: 6.465962
Sum squared resid: 26499.46  Schwarz criterion: 6.478850
Log likelihood: -2286.951  Hannan-Quinn criter: 6.470942
F-statistic: 6.197760  Durbin-Watson stat: 1.198617
Prob(F-statistic): 0.013020
Table 6. OLS, $\Delta s_t$ Regressed on CI$_{t-1}$ and Leads/Lags of I$_t$: 1996-2009

\[ \Delta s_t = d_{00} + \sum_{j=-5}^{5} d_j I_{t-j} + d_6 CI_{t-1} + \varepsilon_t \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{00}$</td>
<td>-0.005125</td>
<td>0.001620</td>
<td>-3.164360</td>
<td>0.0016***</td>
</tr>
<tr>
<td>$d_5$</td>
<td>0.000238</td>
<td>0.000161</td>
<td>1.479773</td>
<td>0.1394</td>
</tr>
<tr>
<td>$d_4$</td>
<td>-0.000180</td>
<td>0.000170</td>
<td>-1.063584</td>
<td>0.2879</td>
</tr>
<tr>
<td>$d_3$</td>
<td>-2.98E-07</td>
<td>0.000170</td>
<td>-0.001753</td>
<td>0.9986</td>
</tr>
<tr>
<td>$d_2$</td>
<td>2.13E-05</td>
<td>0.000178</td>
<td>0.119367</td>
<td>0.9050</td>
</tr>
<tr>
<td>$d_1$</td>
<td>-0.000150</td>
<td>0.000179</td>
<td>-0.839879</td>
<td>0.4013</td>
</tr>
<tr>
<td>$d_0$</td>
<td>-0.000400</td>
<td>0.000179</td>
<td>-2.232171</td>
<td>0.0259**</td>
</tr>
<tr>
<td>$d_{-1}$</td>
<td>-0.000255</td>
<td>0.000179</td>
<td>-1.425209</td>
<td>0.1546</td>
</tr>
<tr>
<td>$d_{-2}$</td>
<td>-6.81E-05</td>
<td>0.000179</td>
<td>-0.380156</td>
<td>0.7039</td>
</tr>
<tr>
<td>$d_{-3}$</td>
<td>0.000226</td>
<td>0.000178</td>
<td>1.274258</td>
<td>0.2030</td>
</tr>
<tr>
<td>$d_{-4}$</td>
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<td>0.000177</td>
<td>-0.402912</td>
<td>0.6871</td>
</tr>
<tr>
<td>$d_{-5}$</td>
<td>-0.000136</td>
<td>0.000169</td>
<td>-0.804526</td>
<td>0.4214</td>
</tr>
<tr>
<td>$d_{-6}$</td>
<td>-1.28E-05</td>
<td>4.32E-06</td>
<td>-2.972399</td>
<td>0.0031***</td>
</tr>
</tbody>
</table>

R-squared         0.041606  Mean dependent var  0.001885
Adjusted R-squared 0.024841  S.D. dependent var  0.023157
S.E. of regression 0.022868  Akaike info criterion -4.699767
Sum squared resid  0.358728  Schwarz criterion -4.615153
Log likelihood     1655.569  Hannan-Quinn criter. -4.667057
F-statistic       2.481708  Durbin-Watson stat  2.058402
Prob(F-statistic) 0.003478