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High and Volatile Treasury Yields in Tanzania:
The Role of Strategic Bidding and
Auction Microstructure

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**High and Volatile Treasury Yields in Tanzania:
The Role of Strategic Bidding and Auction Microstructure**

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Abstract

The observed increase in the level and volatility of Tanzania's Treasury yields in recent years
against an otherwise benign macroeconomic backdrop presented a puzzle for policymakers,
while raising concerns about the fiscal burden of rising debt interest payments and diversion
of bank credit away from the private sector. Using evidence from bid-level data and
supported by theoretical models, this paper argues that oligopolistic bidding through 2005
may have been partly responsible for the rising level of yields; while the high volatility
during 2006-07 could be traced to the emergence of a sharp segmentation of the T-bill
market between sophisticated financial market players (foreign-controlled banks) and a less-
experienced group of investors (domestic pension funds and small banks). An important
policy recommendation that emerges is that public debt managers should avoid micro-
managing Treasury bill auctions by issuing amounts in excess of those offered or by dipping
into oversubscribed segments of the yield curve, as such practices seriously disadvantage the
less-sophisticated (but more competitive) investors vis-à-vis the more sophisticated players.

CONTENTS

I. INTRODUCTION

The sharp increase in Tanzania's Treasury bill (T-bill) rates during 2002-05 and their unprecedented volatility in 2006-07, presented a puzzle to policymakers, particularly when viewed in the context of a significant contemporaneous reduction in Tanzania's external public debt, and in contrast to the relatively stable bank lending and deposit rates. It also raised concerns about rising interest costs for the budget and the adverse impact on banks' incentives to lend to the private sector and to improve efficiency.[2] Moreover, the degree of observed volatility in T-bill yields complicated the authorities' compliance with budgetary and monetary targets, and threatened to impede broader financial market development.[3]

While one would normally expect interest rates on government securities to decline following a public debt reduction and to serve as a benchmark for all other private sector interest rates in the economy, it appears that these relationships have been undermined in Tanzania by particular features of the domestic debt market:

- Shallow government securities market featuring limited direct retail or foreign investor participation.
- Weak repo markets and non-existent secondary trading in government paper, rendering primary market auctions of government securities as the main instrument of monetary policy.
- Government securities held by a few large, and increasingly, private foreign-owned banks. The privatization of the country's largest retail bank in September 2005 to a foreign bank, accompanied by an indirect takeover of the largest commercial bank by another important foreign bank, further concentrated market power in the hands of a few highly experienced players.
- Increasing segmentation, since late 2005, of investors in government securities between highly sophisticated banks dominating the T-bill market (issued in 35, 91, 182 and 364-day maturities), and less experienced pension fund and smaller bank and retail participants purchasing both T-bills and longer-term fixed rate local currency T-bonds (issued in 2, 5, 7 and 10 year maturities).
- Yields on T-bonds extrapolated from the most recent T-bill yields, and thus not very informative about long-term inflationary expectations. The propensity to price T-bonds off recent T-bills yields is also indicative of the low level of financial market expertise of the major bidders in the T-bond segment.
- Use of the same debt instrument (182-day and 364-day T-bills) for liquidity mop-up and government financing operations, with investors not informed about the exact split of an

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[2] See Hauner (2006) on the positive link between banks' cost inefficiency and their share of credit to the public sector.

[3] Since refinancing auctions are announced in face (par) value terms while the net domestic financing (NDF) target is cast in cost (or cash) value terms, volatile yields make it difficult to predict the cash value that would obtain from auctioning a given face value and thereby complicate achieving the authorities' planned NDF target.

auction between liquidity and financing paper. This reflects broader weaknesses in, and the fragmented nature of, public domestic debt management in Tanzania.

- Auction amounts (tender size) advertised by the Bank of Tanzania (BoT) often not observed ex-post – in part due to the need to 'piggyback' liquidity paper issuance onto a tender size based on government funding needs – thus allowing a role for bidders' expectations about the auctioneer's likely cut-off point at a primary auction.[4]

Against the backdrop of these structural features, the rest of the paper is organized as follows. Section II considers the traditional macro-fiscal and demand-supply factors to explain the observed pattern in Treasury yields since late 2002. The examination is then followed by an empirical analysis of bid-level data for Tanzania's T-bill auctions over the period, which suggests that: (i) oligopolistic bidding may have led to higher yields through 2005 and (ii) a sharper T-bill market segmentation between sophisticated (and possibly collusive) bidders and less experienced investors in the context of increased auction micro-management by the BoT may have been behind the high volatility in yields witnessed since then. Section III formalizes these findings into (i) a stylized model of Cournot-type oligopolistic bidding for the 2002-05 period, and (ii) an original 'segmented market' model replicating the particular structural aspects of Tanzania's T-bill market and auction system prevailing during the 2006-07 period. Section IV concludes with some policy suggestions on reining in the market power of large investors, including through adherence to international best practice in auction design and management.

II. EMPIRICAL OBSERVATIONS FROM TANZANIA'S T-BILL MARKET

T-bill rates in Tanzania rose from a low of 3 percent in late 2002 to an average of 15 percent by end-2005, and became extremely volatile thereafter, with peaks and troughs in successive months almost 10 percentage points apart (Figure 1). The level and volatility of T-bill rates in Tanzania is also high relative to other countries (Table 1 and Figure 2).


Figure 1: Level and volatility of T-bill yields

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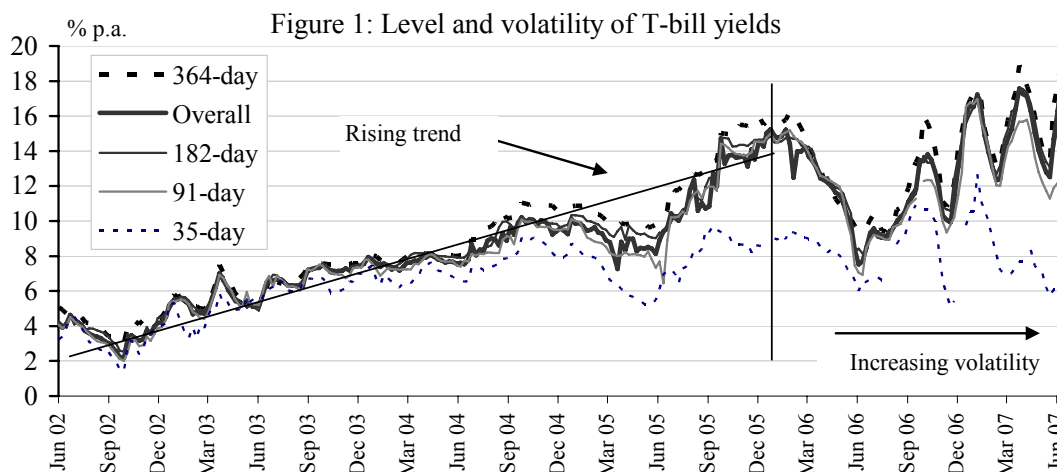
[4] The BoT conducts all government securities auctions on behalf of the Ministry of Finance (MoF). See Annex I for details on the maturity structure and technical aspects of the T-Bill auction system in Tanzania.

Figure 2: Nominal T-bill rates (percent)
(median values for country groups)

Table 1: Volatility of nominal interest rates
(coefficient of variation)

|	OECD	non-OECD	SSA	Tanzania
Deposit rate	18	27	18	33
Government yield	17	30	27	42
Lending rate	15	13	12	18

Source: Authors' calculations using IFS data for 2000-2005
Note: For country groups, median values are reported
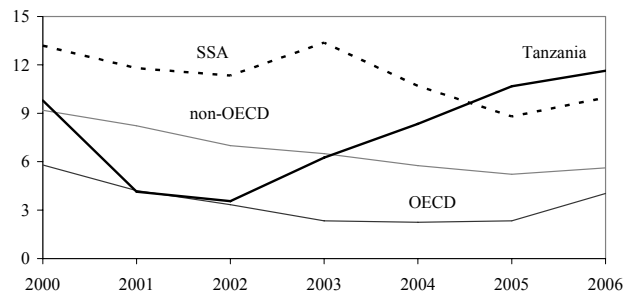
The rising and volatile short-term rates have also spilled over into yields on long-term T-bonds, as the relatively less sophisticated investors (mostly pension funds) who dominate this yield curve segment have typically priced T-bonds off the prevailing 364-day T-bill rate adjusted upward for a flat maturity premium. The resulting yield curve has almost always been upward sloping and, therefore, not very informative about long-term inflationary expectations (Figure 3).

Figure 3: Tanzania Yield Curve 2003-2007 (% p.a.)
(based on simple average of yields obtaining in auctions held in quarters-ending)
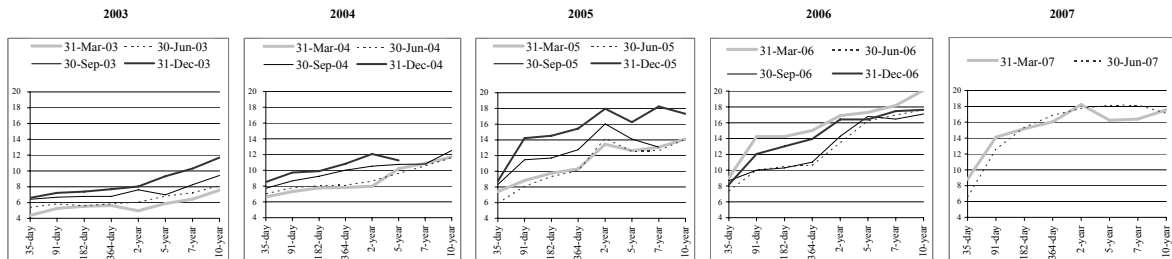
To explain the observed pattern in T-bill yields – both the rise in level (2002-05) and in volatility (2006-07) – we first consider traditional macro-fiscal and demand-supply arguments followed by an examination of microeconomic evidence from Tanzania's T-bill auctions.

A. Traditional Macro-Fiscal and Supply-Demand Explanations

The 12 percentage point increase in yields from end-2002 through 2005 appears to be greater than what could be explained by traditional factors: higher riskiness of public sector debt, exchange rate depreciation, and inflationary expectations. The narrowing of the gap between bank lending rates and T-bill yields (Figure 4) would seem to suggest an implausible increase in public sector risk (or issuer risk premium) relative to the risk on private lending.[5] Furthermore, discussions with market participants during this period revealed consistently

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[5] Although the credit environment has improved notably over the past few years, private risks still remain high, and are perceived as such, in relation to the default risk on government securities.

positive perceptions about the stability of the financial system and the macro economy and inflationary expectations appeared to be well-anchored (Figure 5). Last but not least, the historical association between T-bill rates and currency depreciation in Tanzania appears indeterminate, if not counterintuitive (Figure 6).

Figure 4: Lending,deposit and T-bill rates
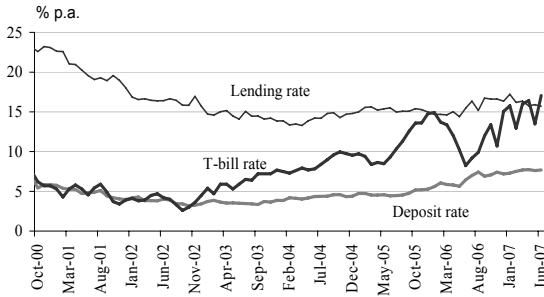
Figure 5: Real interest rate(t) = [1+nominal(t)]/[1+inflation(t+3)]
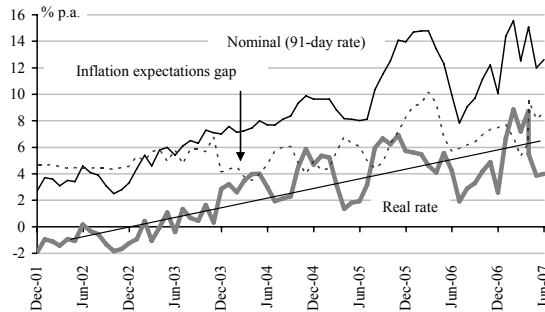
First-order supply-demand explanations in a competitive setting seem more promising. On the supply side, domestic debt issuance increased markedly between 2001 and 2005 on account of both higher sterilization operations and budgetary financing (Figures 7).[6] The short duration of government securities permitted a quick and unfavorable repricing of debt, as is evident from the comovement of the average interest rate with the stock of outstanding securities (Figure 8).

Figure 6: Correlation of T-bill yields with lagged *current* (future) exchange rate depreciation = -0.14 -*0.16* (-0.17)

On the demand side, the rapid increase in private sector lending since 2003 has reduced commercial bank funds traditionally available for investment in government securities (Figure 9).
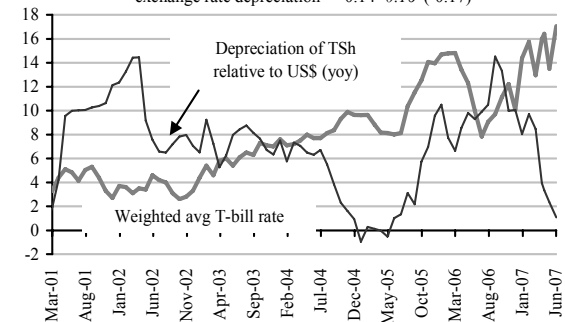
Figure 7: Liquidity vs. financing issuance
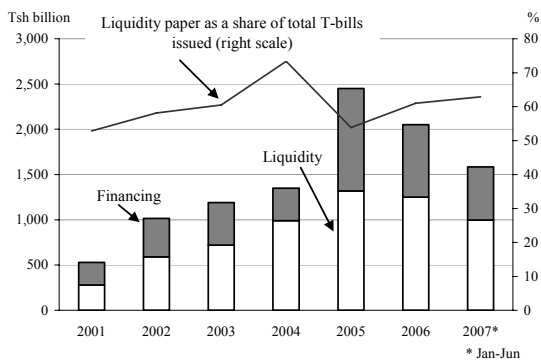
Figure 8: Average interest rates and outstanding stock of securities

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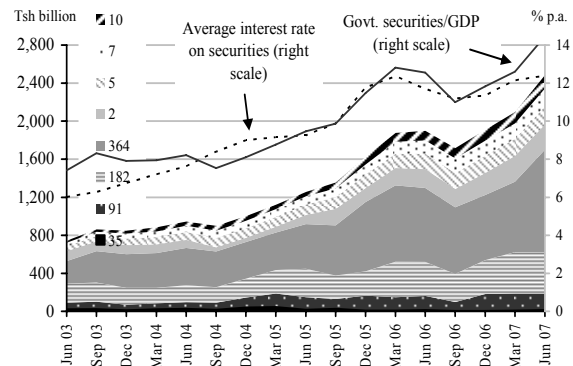
[6] Gross liquidity paper sales rose 43 percent year on year between 2001 and 2005 reflecting, mainly, the need to sterilize large aid inflows. This relatively strong growth in the supply of liquidity paper was accompanied by a sharp increase (over 2 percent of GDP) in financing paper issuance in the second half of 2005 due to drought and election-related spending.

TSh billion   Figure 9: Shift in banks' asset composition
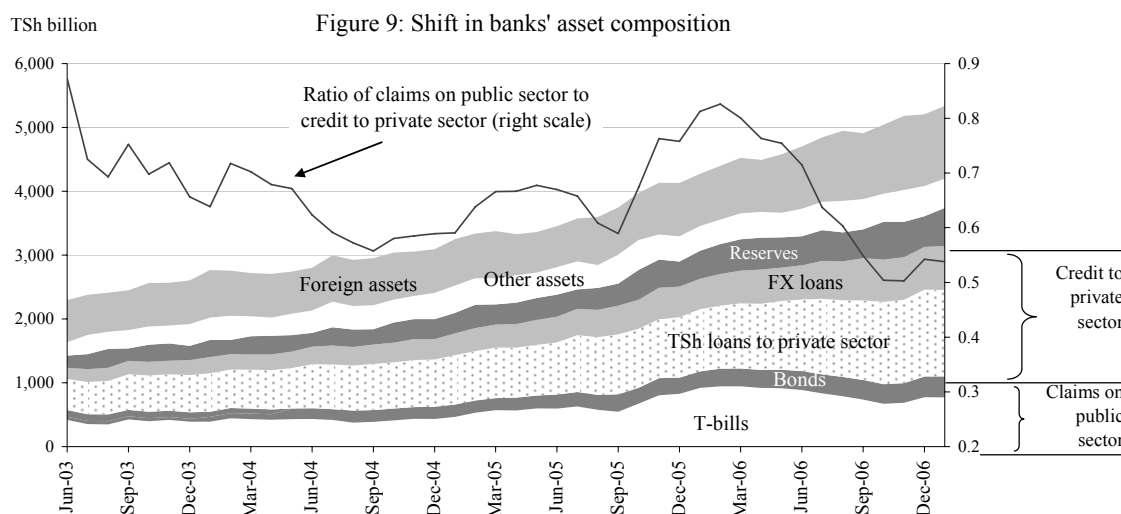
While the aforementioned factors are likely to have contributed to the observed increase in yields in Tanzania, the highly concentrated holdings of government securities (as discussed below) and the puzzling pattern of volatility of yields during 2006-07 suggest that factors such as market power, strategic bidding and auction microstructure may also be at play. To see if this conjecture is empirically justifiable, we examine below some evidence from bid-level data on Tanzania's weekly T-bill auctions from January 2002 to June 2007.

B. Market Structure Explanations of High and Volatile Yields

T-bill holdings in Tanzania – as in most SSA countries – have been, and remain, highly concentrated, with a few large commercial banks generating the bulk of demand (Table 2).[7] The banking sector accounts for about 70 percent of all T-bill holdings suggesting relatively limited successful retail and institutional participation. There is also some evidence of recent foreign portfolio investment in the T-bill market which, due to restrictions on direct nonresident ownership of government securities, has been routed through banks (mainly foreign), further contributing to their market power.

To better understand the role of market structure in the determination of Tanzania's T-bill yields, it is important to briefly trace the evolution of the banking system. The process of banking sector deregulation and privatization commenced in Tanzania in the late 1990s and gained momentum after the turn of the millennium. Subsequently, many foreign banks were drawn in, against an increasingly favorable macroeconomic and financial sector backdrop. Consequently, competition in the sector increased, reflected in the provision of significantly improved banking services; credit to the private sector recovered after having almost

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[7] Čihák and Podpiera (2005) conclude that foreign banks in East Africa are effectively insulated from competition due to their size and international links. OECD (2002) cites bank dominance as one of the challenges to developing efficient markets for government securities in emerging countries. Dohdia (2007) points to the high concentration of short-term domestic debt in the hands of commercial banks exercising monopoly power as a factor contributing to high real interest rates in low-income countries. Glaessner and Ladekarl (2001) note that reliance on the banking system to mobilize savings for the purchase of government securities has proved to be costly for many governments.

completely dried up in the late 1990s; and activity rose in the corporate bond and inter-bank foreign exchange and money markets.

However, greater foreign participation also brought greater challenges for the central bank, both in terms of bank supervision and the conduct of auction-based open market operations. The challenge became particularly daunting when, in the second half of 2005, a substantial share of banking system assets passed into the hands of highly sophisticated foreign bank managers. This happened following the indirect takeover (in July 2005) of the biggest commercial bank by a foreign bank already operating in the country; and the sale (in September 2005) of the country's largest retail bank (and by far the biggest investor in T-bills). The impact on the T-bill market of the dramatically more sophisticated financial sector that has emerged can be surmised from a comparison of the successful bid shares of various investor groups over time (Table 3).

Table 2: Median Herfindahl indices for bank deposits and government securities holdings

	Bank deposits	Government securities
OECD countries	0.08	0.13
non-OECD countries	0.25	0.34
Sub-Saharan Africa	0.38	0.48
Tanzania	0.22	0.47

Source: Authors' calculations using Bankscope data for 1995-2005
Note: An index >0.18 is considered indicative of high concentration

Table 3: Bidder profile

	2002-05	2006-07
Retail investors/brokers	4.3	5.8
Institutional investors	21.0	23.6
Small banks/NBFIs	11.9	12.6
Large banks	62.9	58.1
Foreign-controlled *	10.0	46.3
Locally-controlled	52.9	11.8

* Reflects privatization and indirect takeover

The T-bill market in the 2002-05 sub-period was dominated by a dispersed group of domestic (and regional) banks and pension funds, with major foreign banks claiming only a 10 percent share. This share had risen to almost half in 2006-07, punctuated by a qualitatively higher concentration due to the assumption of indirect control by an existing foreign bank of the largest commercial bank in the country. Below, we present some empirical observations that help explain how these two different market structures could have contributed to different bidding incentives and how the latter could, in turn, have driven the observed phenomena of rising yields (2002-05) and high volatility (2006-07), respectively. This evidence also directly motivates the theoretical models in Section III.

Bidding behavior during 2002-05: Cournot oligopoly explanation for rising yields

As observed earlier, the T-bill market in this period was dominated by three large banks (with a combined market share of 53 percent), followed by pension funds (21 percent) and other small banks/NBFIs (12 percent). Although most of these investors had relatively little experience in treasury operations – ruling out, presumably, the possibility of explicit auction manipulation – the possibility of the three largest banks using some degree of market power through strategic bidding cannot be ruled out. Indeed, the three large banks also sat on significant amounts of non-tradable recapitalization bonds issued by the government, bearing coupons linked to T-bill yields, increasing banks' incentives to keep the yields high.[8] As we

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[8] This rendered the banks' overall interest incomes even more sensitive to individual bidding decisions, creating an additional powerful incentive for strategic bidding.

show below, there is some support in the data for bidding behavior akin to a *Cournot oligopoly*.[9]

Our first piece of evidence comes in the form of an unusually close association between *gross* T-bill issuance and yields during 2002-05 (Table 4).[10] While a strong comovement between *net* issuance and yields would be expected in a competitive T-bill market, only market power forces can materially explain a strong correlation between gross issuance and yields.[11] The existence of such forces would predict that investors bid strategically in the pursuit of an optimal outcome at each new auction, even when they are contemporaneous recipients of large T-bill redemptions. In such a situation, a cash-rich investor could either try and undercut everyone else and take the entire auction; or he could behave more strategically, noting the adverse impact of such aggressive bidding on future Treasury yields and, hence, on the return on other assets linked to those yields.

Table 4: Correlation between yields and -

	2002-05	2006-07
Gross overall issuance	0.68	0.40
Gross financing paper issuance	0.41	-0.26
Gross liquidity paper issuance	0.63	0.60

Next, we look at evidence of the absence of price-based competition, as would be implied by Cournot (or quantity-based) competition. This is important to show as the purpose of auctions is to encourage competition on both quantities and prices. Price competition requires investors (i) to have asymmetric incentives due to say differences in liquidity positions or opportunity cost of funds; and/or (ii) to form different priors about market yields. These conditions, are unlikely to have been strongly applicable in Tanzania during 2002-05.

On (i), the existence of large recapitalization bonds and abundant liquid assets on the balance sheets of the three large banks implied a close alignment of incentives among them to keep the yields high. For (ii), the generally weak treasury experience of these locally-managed banks would have precluded the forming of 'sophisticated' priors about the appropriate level of yields and, in most cases, their bids would have been guided by previous yields.[12] With

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[9] In a Cournot oligopoly, the representative investor with market power chooses supply (funds to bid) after taking into account the impact of that decision on the overall market price and hence his profitability. With each investor doing the same, and assuming no collusion, the equilibrium price converges to that obtaining under perfect competition as the number of investors increases.

[10] Importantly, this association does not endure in the highly volatile period of 2006-07.

[11] Since liquidity and financing paper issues in Tanzania are bundled together and auctioned through the same instruments (182-day and 364-day T-bills), it is difficult for investors to judge if a particular issue is intended to temporarily mop-up excess liquidity, rollover redeeming maturities, or finance the budget deficit. The signal extraction problem this creates for investors may also be a factor linking gross issuance to yields.

[12] Note that there is no secondary market price for T-bills to guide bidders, which prevents the 'flow' of sophistication across investor groups. If there were a secondary market, an additional pricing benchmark would be available to less experienced investors. Moreover, although the authorities efforts to develop benchmark T-bond issues are commendable, the expected benefits thereof have been elusive, given the absence of secondary trading, and the continued pricing of T-bonds off T-bill auctions. It is possible that an overhaul of Tanzania's primary dealership arrangements for government securities, which is beyond the scope of this paper, is needed before secondary trading can pick up.

meaningful price-based competition ruled out, banks would have likely competed on quantities (i.e., on bid size) with each bank submitting multiple bids (as permitted under Tanzania's auction rules) around some known benchmark yield and choosing the desired bid size for each bid bracket. Annex II illustrates how such quantity-based competition might occur in a *discriminatory* price auction system of the kind in place in Tanzania.[13, 14]

Empirical evidence in support of Cournot-type strategic bidding

To substantiate the hypothesis of no-price-based competition, we examine the extent of the correlation between yields bid by the major investors. The computation of bid yield correlations between the three large banks reveals very high values (Table 5), suggesting, indeed, that investors appeared content on bidding close to a commonly understood benchmark, rather than bidding purely on the basis of their respective liquidity positions. The high correlations between the weighted average yields bid and the previous week's clearing (weighted average) yield confirms the latter as the most likely benchmark (Table 6).

Table 5: Correlation between weighted average yields bid by the three large banks (B, C, M) at auctions during 2002-05.

Bill type		C	obs.	B	obs.
35	B	0.975	21	--	
	M	0.983	50	0.983	26
91	B	0.994	28	--	
	M	0.984	57	0.994	25
182	B	0.988	39	--	
	M	0.981	49	0.991	41
364	B	0.997	48	--	
	M	0.990	55	0.994	48

obs. denotes number of bid pairs available for computation of corresponding correlation coefficient.

Table 6: Correlation between average yield bid and the weighted average yield obtaining at previous auction (2002-2005)

| Bill type	Correlation	obs.
35	0.952	116
91	0.966	124
182	0.980	126
364	0.985	132

Next, the presence of quantity-based strategic bidding appears to be confirmed by the negative relationship between lagged yields and bid cover ratios up until 2005 (Figure 10,

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[13] In a discriminatory price system, each successful bid is paid the corresponding quoted price rather than a single cut-off price. Thus if Bank A had put in three successful bids – TSh 10 billion at 7%, TSh 15 billion at 8% and TSh 7.5 billion at 9% – and 9% became the cut-off yield, Bank A would receive a weighted average yield of 7.9% and not 9% (as would be the case in a uniform-price auction). The popularity of discriminatory (vs. uniform) auctions partly stems from their lower perceived vulnerability to collusive bidding (Bartolini and Cottarelli, 1997) although some studies found evidence that uniform-price auctions encourage more competitive bidding and produce a broader distribution of auction awards (Malvey and Archibald, 1998).

[14] Note that unlike T-bills, T-bonds are auctioned on a uniform price basis. However, as is apparent from Figure 3, T-bond yields have also been as volatile as T-bills, suggesting, therefore, that the choice of uniform vs. discriminatory auction is unlikely to be a differential factor in driving volatility. The key problems are investors being unable to price term instruments and thus pricing T-bonds off T-bill-auctions. Unless the more fundamental problems in the conduct of T-bill auctions and the structure of the financial market are addressed, switching the auction mode from discriminatory to uniform is unlikely to prove helpful. In fact, a uniform pricing system for T-bills – the benchmark interest rate for T-bonds – could exacerbate manipulative tendencies by increasing the incentive for collusion.

left column).[15] With each large investor aware of the endogeneity of yields to the amount bid, lower yields at previous auctions would create incentives for smaller bids at subsequent auctions in an attempt to keep yields high or prevent them from falling further.

Figure 10: Correlation between lagged yields and bid-cover ratios

Jan 2003 - Dec 2005 (all auctions)   Jan 2006 - Jun 2007 (all auctions)
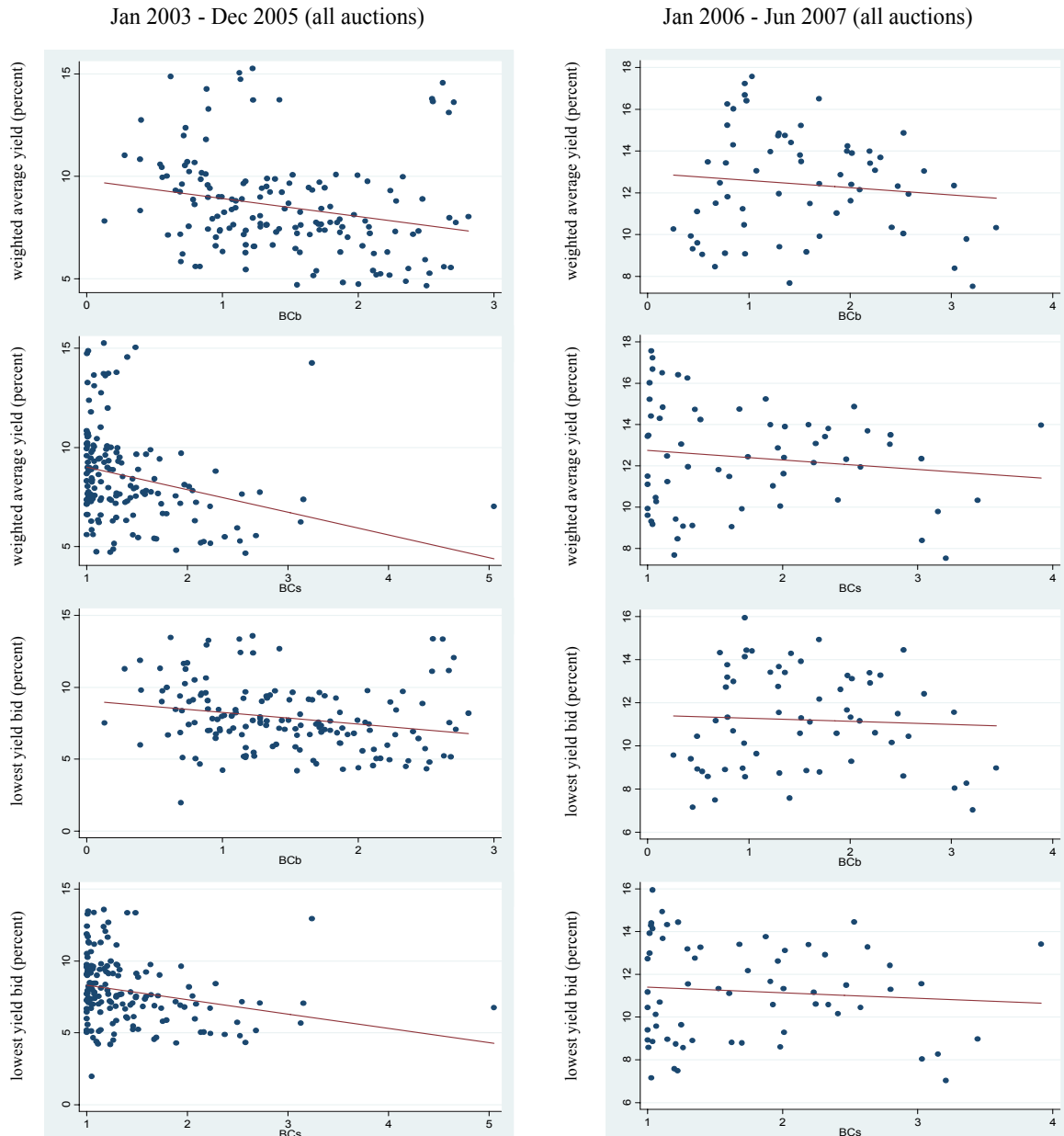
The foregoing suggests that a Cournot oligopoly characterization of the incentive and bidding structure of the three large banks during this period is not implausible. Importantly, there is

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[15] The standard bid cover ratio (BCb) is defined as the total amount of funds bid by investors at an auction divided by the total amount announced by BoT. A modified definition of bid cover ratio (BCs) is the total amount of funds bid by investors divided by the total amount issued. Since BoT usually issues amounts that are different from those announced it is useful to use both ratios.

reason to believe that other major investors – especially pension funds and foreign banks – could not have altered or challenged this structure. Tanzanian pension funds have been generally found to be backward-looking in their bid-setting behavior, while the foreign banks' share was too small at the time to make a substantial competitive dent. Thus, oligopolistic bidding by the three large banks is likely to have dominated other competitive forces in the market. As the supply of T-bills increased during the period, banks took advantage of their market power which translated into a sharp increase in yields.

Bidding behavior during 2006-07: 'Segmented market' explanation for rising volatility

The oligopolistic character of the market discussed above appears to weaken significantly in 2006-07 (see Figure 10, right column) following the emergence in late-2005 of a powerful group of six highly sophisticated foreign banks and the ensuing shift in market structure.[16]

The exact implications for Tanzania's T-bill market (and yields) of such a shift is not straightforward to assess. On the one hand, the small size of this group employing highly experienced treasury operations and controlling about half of the banking system assets, together with their influence in the foreign exchange market and the ability to borrow funds abroad and deploy them in the local T-bill market, may have favored collusive behavior to manipulate auctions (see Table 7 below). On the other hand, the new structure may have engendered greater competition as the earlier dominance of the three large local banks was dismantled, much of the stock of the T-bill-linked recapitalization bonds had been redeemed, and the high level of yields prevailing by end-2005 increased the room for more competitive bidding.[17]

Revisiting the yield patterns in Figure 1 suggests that 2006-07 was a period of high volatility around the 15 percent level of yields that had obtained by end-2005. Although this does not allow an unambiguous statement about the overall competitive effect of increased foreign bank participation on T-bill yields, it does suggest a clear break from the earlier oligopolistic equilibrium. The sharp fluctuations in yields, in fact, point to an equilibrium that may have alternated between less competitive (and possibly collusive) episodes and those marked by highly competitive bidding. As the empirical analysis below (formalized in the market segmentation model in Section III) shows, this alternating pattern is best understood in the context of the increased auction micro-management that characterized central bank operations during this period.

The high net issuance of paper (both financing and liquidity) in late 2005 had left the BoT with the difficult challenge of rolling over a much larger stock of T-bills than ever before. At the same time, the BoT's monetary program, supported by the IMF, was based on quarterly reserve money targets which, given the limited use of repos and the central bank's aversion

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[16] Furthermore, successive week-on-week increases in T-bill yields occurred on 23 occasions during fiscal year 2006/07, 14 of which coincided with successive week-on-week increases in the bid-cover ratio.

[17] The stock of such special bonds fell from an average of over 16 percent of total T-bills and T-bonds in 2002/03 to about 5 percent by 2005/06. Moreover, since most of these special bonds had an interest rate floor (7 percent) and ceiling (13 percent), the level of interest rates after end-2005 – averaging above 15 percent – rendered the interest income consideration on these bonds irrelevant at the margin.

to selling foreign exchange, inevitably implied the need for large issuance of T-bills at end-quarter auctions (Figure 11). The combination of the roll-over and monetary target compliance imperatives led to the emergence of 'pressure points' in the T-bill issuance profile (Figure 12).

Figure 11: End-quarter reserve money contractions

Figure 12: Pressure points in issuance profile
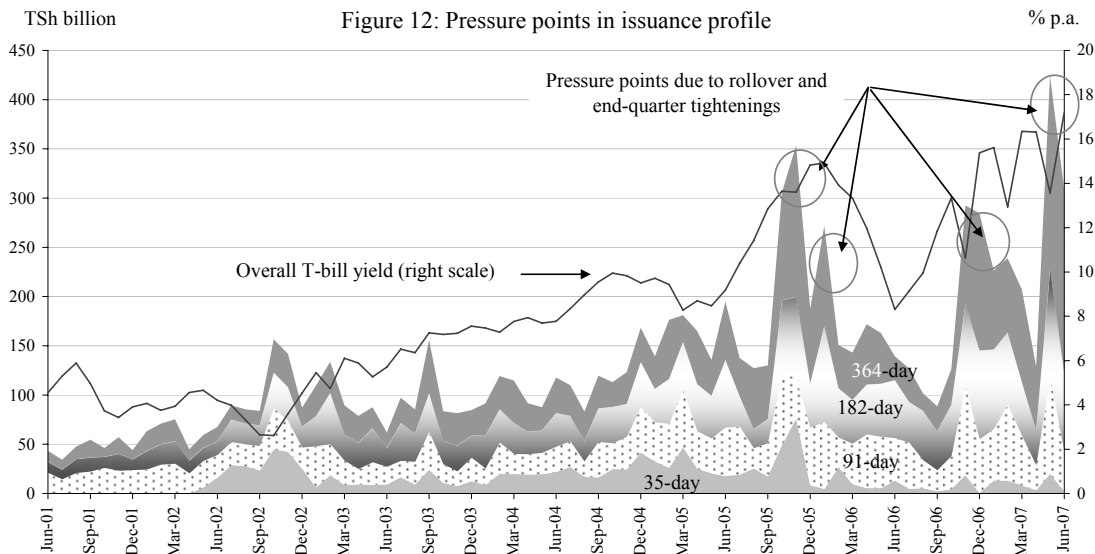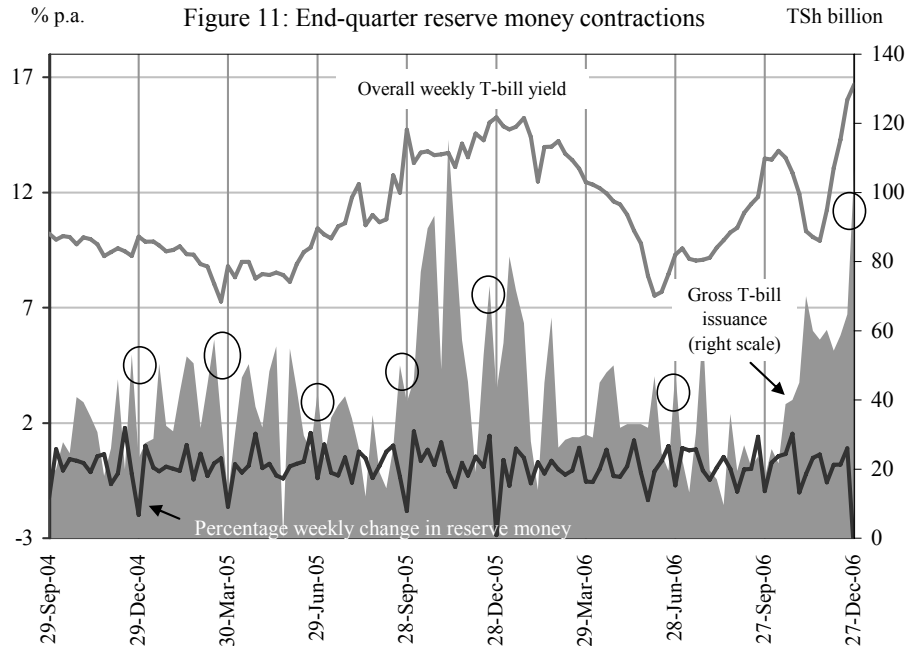
The existence of these pressure points was not publicly revealed, ex ante; nor were the advertised auction amounts adjusted upwards in advance of a 'pressured' auction. Instead, the BoT had a policy of dipping into oversubscribed auctions around the pressure point dates to mop up the required liquidity. However, interviews with market players revealed that all the large foreign banks and at least two small local/regional banks were able to 'anticipate' well both the timing and size of these pressure-point interventions – apparently, they did this by maintaining a redemption profile of auctioned securities. Consequently, they had adopted a strategy of bidding large amounts for the longest-term paper (in the hope of locking into

high rates for longer periods) at very high yields at exactly the auctions BoT hoped to intervene in (Figure 13).

Figure 13: Shift in bidding to longer-term paper at pressure points and quarter ends
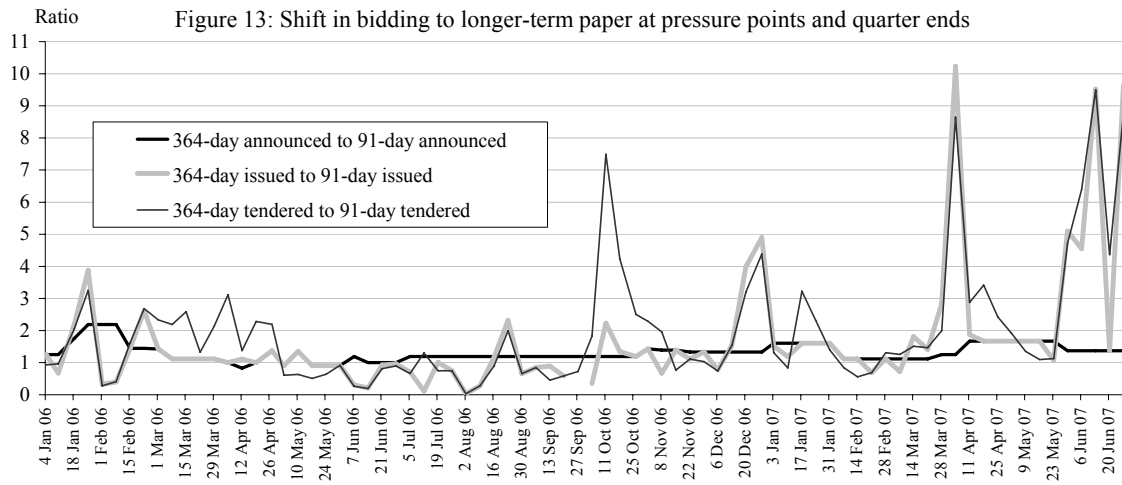
Monetary management was further complicated in 2006-07 by what is now believed to be short-term portfolio inflows into the T-bill market intermediated through foreign banks to circumvent the restrictions on direct nonresident ownership of government securities.[18] The sale of foreign exchange that coincided with the inflows upset the traditional trade-related seasonality in the foreign exchange market and was accommodated by BoT through domestically sterilized purchases.[19] The knowledge of BoT's 'sterilization reaction function', however, gave the foreign banks the ability to create 'pressured auctions' by bringing in funds from abroad, selling the associated foreign exchange to BoT, and then forcing the latter to issue sterilization T-bills which banks could purchase with the local currency counterpart.

Overall, the size, sophistication, and unique positioning of the foreign banks vis-à-vis capital inflows rendered this group particularly well-placed to manipulate the pressured T-bill auctions through collusion. It is important to note, however, that due to a particular auction rule – no bidder allowed to bid in excess of the total offered amount – this would have been true even in the absence of explicit collusion between the banks. The intuition of this statement lies in the relation between the size of pressured auctions and the offered amounts wherein actual issuance by the BoT at pressured auctions during 2006-07 has often exceeded the amount offered by a wide margin. With each individual investor's aggregate bid limited to the announced amount, there would be little incentive to outbid another bank in the group in an attempt to take the entire auction.[20] Put differently, with the actual issuance at pressured auctions exceeding the amount announced, the auction bidding rule would have nudged the behavior of individual banks towards that obtaining in a collusive equilibrium, without the banks needing to collude explicitly.

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[18] The funds were converted by the banks into local currency deposits (by selling the foreign exchange in the inter-bank market) which were then invested in the T-bill market. At the end of the period, the resident foreign bank would pass the T-bill yield abroad in the form of an interest payment on the deposit (retaining a margin).

[19] This phenomenon was also witnessed in Uganda in mid-2007.

[20] In fact, on a few occasions when this did happen (i.e. a bid in excess of the offered amount was received), the central bank rejected the bid, perhaps, inadvertently reducing the incentive for more competitive bidding.

Table 7 summarizes the nature of segmentation between the two broad investor groups operating in the T-bill market in 2006-07 drawing on interviews with the authorities and major players in the government securities market:

Table 7. Main characteristics of investor groups in T-bill market

	Sophisticated foreign or foreign-controlled banks	Pension funds, locally-controlled and small banks, brokers and retail investors
Number/share of T-bill market	Six/46 percent	Numerous/54 percent
Ability to extract signals from published auction information	High	Generally low
Ability and incentive to collude, overtly or covertly	High	Low
Ability to generate redemption profile of issued securities and to anticipate key rollover pressure points (and the central bank's 'unannounced' interventions)	High	Generally low
Knowledge and ability to take advantage of BoT's sterilization reaction function	High	Low

Empirical evidence in support of market segmentation

To confirm the presence of segmented markets, we analyze the correlation between bid yields of four foreign banks (denoted B1, B2, B3, B4), and the four major investors among the 'naïve' group (denoted N1, N2, N3, N4) for auctions of 364-day bills during 2006-07.[21] We find evidence of stronger 'within group' correlation than 'between groups' (Table 8).[22]

Table 8: Correlations between investors' bid yields

	B2	B3	B4			N2	N3	N4			N1	N2
B1	0.97	0.85	0.79		N1	0.96	0.92	0.99		B1	0.77	0.78
B2		0.93	0.85		N2		0.95	0.99		B2	0.74	0.80
B3			0.94		N3			0.94		B3	0.57	0.62
		average	*0.89*				*average*	*0.96*			*average*	*0.71*

Periods during which the amounts issued were aligned with the offered amounts saw yields declining sharply (Figure 14), while auctions at which the amounts issued exceeded the offered amounts appear to have invited potentially collusive/manipulative bidding by foreign banks manifested in their higher share of successful bids (Table 9). Auctions at which the BoT issued more than it announced appear more vulnerable to manipulation as sophisticated investors were able to anticipate the size of actual issuance and skew their bids towards longer-term paper along with raising their bid yields. At auctions where the amount issued

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[21] The selection is for parsimony; including the entire set of correlations would not change the conclusions.

[22] Using bid-level data, Caputo Silva (2002) finds evidence of distinct bidding behavior across different categories of bidders, with foreign institutions obtaining higher profits in the Brazilian Treasury auctions.

was equal to the announced, the informational (and hence manipulative) advantage that colluding banks have over the naïve investors disappears.[23]

Table 9: Share of foreign banks' bids in total successful bids (%)
(364-day T-bill auctions; 2006-07)

	Issued > Announced	Issued = Announced
Sample mean	72.91	63.71
Standard deviation	11.76	23.79
Observations	17	34
t-value (p-value) for difference of means test = 1.48 (0.07)		

Why then has the BoT not issued the offered amounts or why were the large pressure point auctions not pre-announced? Surprisingly, the existing policy literature does not say much (from a theoretical perspective) about why the auctioneer should not intervene substantially at an auction except that the practice of issuing what is announced enables participants to prepare funds better and improves the credibility of auctions.[24] However, many African central banks, including in Tanzania, consider this an inadequate reason for strict observance of announced amounts and are primarily concerned with auction manipulation by a few large investors, the risk of which they believe increases with the predictability of the auctioneer's issuance strategy. It is the discussion above and the market segmentation model below that show the benefits of being transparent and adhering to the announced amounts in a low-income country setting. As argued, this transparency helps dismantle a particular market structure by crowding in naïve but competitive bidders and by reducing the market power of potentially collusive investors.

Figure 14: Correlation between yield and issued-to-announced ratio

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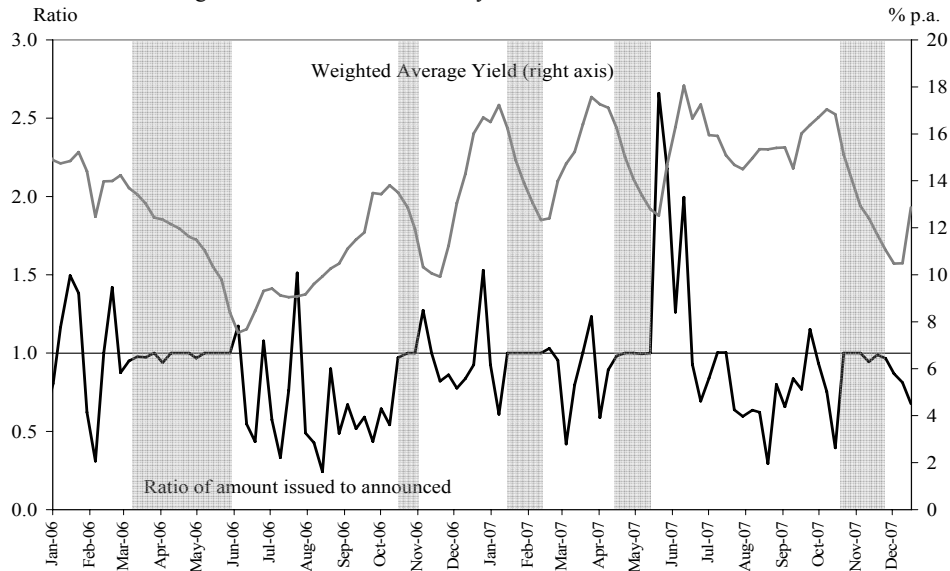
[23] Keloharju *et al.* (2002) present evidence that Finnish Treasury auctions are part of a repeated game setup where bidder behavior is driven by private information rather than market power. Elsinger and Zulehner (2007) find that award concentration in Austrian Treasury auctions increases with uncertainty, and point out that asymmetries across bidders play an important role in the strategic behavior of bidders. According to Danmarks Nationalbank (2003), Treasury auctions with a limited number of participants entail a greater risk of strategic behavior up to the actual issuance compared to issuance via tap sale.

[24] See for example World Bank (2001) and World Bank (2007).

III. THEORETICAL MODELS OF STRATEGIC BIDDING AT T-BILL AUCTIONS

The empirical observations discussed above can be formalized with two models: one of oligopolistic behavior, to explain the increase in level up until late 2005; and the other of a segmented market (between sophisticated and naïve investors), to explain the increase in volatility in 2006-07.

A. Oligopolistic Bidding Model: Explaining rising level of yields during 2002-05

To demonstrate the impact of high concentration of T-bill holdings on yields in a non-collusive environment, we construct a one-period n-bank oligopoly model. Risk-neutral banks compete to provide funds to the government G in exchange for T-bills (bearing return r_G) and private sector loans L.[25] We assume that, in the short term, L is fixed but a proportion of the loan portfolio $\overline{L}^r$ (repriceable loans) carries a variable rate of interest $r_G + \xi$ (where ξ is a fixed premium above r_G which serves as the benchmark rate for loan pricing). The remainder $\overline{L}^n$ (non-repriceable loans) carries a fixed rate $\overline{r}_L$.[26] In addition to T-bills and private sector loans, banks hold government recapitalization bonds B the return on which is tied to T-bill rates. The bonds are assumed to back the banks' equity capital E one to one.[27] On the liabilities side, banks attract private sector deposits D on which they pay interest rate r_D which we assume is the only cost faced by the banks. Given the dominance of a few large banks in the T-bill market during the 2002-05 period, we assume that the government issues T-bills only to banks and abstract from the longer-term bonds which, as discussed above, are priced in any case off T-bill yields.

Bank i's optimization problem is:

$$\max_{G_i} (r_G + \xi)\overline{L}_i^r + \overline{r}_L \overline{L}_i^n + r_G G_i + r_G \overline{B}_i - r_D D_i$$

subject to

(i)   bank's balance sheet constraint: $\overline{E}_i + D_i = G_i + \overline{L}_i + \overline{B}_i$ where $\overline{E}_i = \overline{B}_i$ and $\overline{L}_i = \overline{L}_i^r + \overline{L}_i^n$;

(ii) government demand for funds: $r_G = f(G)$, $f' < 0$, $f'' < 0$ $\forall G$ where $G = \sum_{i=1}^{n} G_i$;

(iii) bank's cost of funds: $r_D = q(D)$, $q' > 0$, $q'' > 0$ $\forall D$ where $D = \sum_{i=1}^{n} D_i$;

(iv) aggregate conditions: $\overline{L} = \sum_{i=1}^{n} \overline{L}_i$, $\overline{B} = \sum_{i=1}^{n} \overline{B}_i$.

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[25] For every dollar that banks provide, they get $1 + r_G$ worth of T-bills which are recorded at cost value in government's public debt statement.

[26] This captures the differential speed of asset repricing in a situation where banks cannot liquidate their private sector loans or increase their lending rates in the short term.

[27] We abstract from holdings of cash or statutory reserves.

f and q are continuous twice-differentiable strictly concave and convex functions, respectively. The concavity of f reflects the fiscal nature of the government's demand for funds: i.e., G is determined by the size of the fiscal deficit and the need for mopping up liquidity. The convexity of q reflects the increasing marginal costs of mobilizing deposits.

The first order condition for bank i is:[28]

$$f'\overline{L}_i^r + r_G + f'G_i + f'\overline{B}_i - r_D - q'D_i = 0$$

Aggregating over n banks:

$$f'\overline{L}^r + nr_G + f'G + f'\overline{B} - nr_D - q'D = 0$$

or

$$r_G - r_D = \frac{1}{n}\left(-f'G\left(1 + \frac{\overline{L}^r}{G} + \frac{\overline{B}}{G}\right) + q'D\right) \tag{1}$$

where $\dfrac{1}{n}$ captures the non-collusive oligopoly aspect of the equilibrium.

Since we do not specify the functional forms for q and f, we use (1) as the stylized exposition of the 'strategic' behavior by banks imbedded in the interest rate spread $r_G - r_D$. Noting that $\dfrac{1}{f'G}$ and $\dfrac{1}{q'D}$ are the semi-elasticities ε_G and ε_D of f and q with respect to G and D, respectively, with $\varepsilon_G < 0$ and $\varepsilon_D > 0$, the rule governing the equilibrium spread between T-bill and bank deposits rate can be written as:

$$r_G - r_D = \frac{1}{n}\left(-\frac{1}{\varepsilon_G}(1 + \lambda\phi + \gamma) + \frac{1}{\varepsilon_D}\right) \tag{1'}$$

where $\lambda = \dfrac{\overline{L}^r}{\overline{L}}$, $\phi = \dfrac{\overline{L}}{G}$, and $\gamma = \dfrac{\overline{B}}{G}$

Thus, a larger spread between r_G and r_D and, given that r_D is increasing in G, a higher r_G obtain when:

- T-bill holdings are concentrated (i.e., n is low);
- the government's demand for funds is relatively inelastic with respect to the interest rate paid thereon (i.e., $|\varepsilon_G|$ is low);

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[28] Because of the linear sum, the partial and total derivatives of f and q are identical.

- the private sector's demand for bank deposits is relatively inelastic with respect to the return on deposits (i.e., ε_D is low);
- the ratio of banks' loans to their holdings of government securities and the share of repriceable loans in the banks' loan portfolio are high (i.e., λ and ϕ are high);
- the stock of variable-interest government recapitalization bonds is high relative to banks' holdings of T-bills (i.e., γ is high).

Under perfect competition (i.e., $n \rightarrow \infty$) and subject to the simplifying assumption of zero fixed costs, the spread would disappear and r_G would converge to r_D.[29]

The equilibrium response of the spread between T-bill and bank deposit rates to an exogenous change in G (such as an increase in the government financing requirement) is derived by differentiating the right-hand side of (1) with respect to G:

$$\frac{\partial(r_G - r_D)}{\partial G} = \frac{1}{n}\left(-f'(1 + \sigma_G(1 + \lambda\phi + \gamma)) + q'(1 + \sigma_D)\right) \qquad (2)$$

where $\sigma_G \equiv \dfrac{f''G}{f'} > 0$ is a measure of concavity of f (i.e., the elasticity of f' with respect to G) and $\sigma_D \equiv \dfrac{q''D}{q'} > 0$ is a measure of convexity of q (i.e., the elasticity of q' with respect to D).

With the right-hand side of (2) unambiguously positive, the underlying bank behavior imbedded in (2) implies that banks would be willing to increase their supply of funds to the government only if the rate of return on government securities increases faster than the deposit rate. The more concentrated the holdings of government securities, the faster the rate of increase.

The rule (1) governing the equilibrium spread between T-bill and bank deposit rates and its response (2) to an increase in the issuance of government securities can together help explain the rising T-bill rate trend and the widening of the spread in the wake of the steady increase in the supply of T-bills between 2001 and 2005 on account of both higher sterilization operations and budgetary financing. This result obtains independently from any higher risk premium related to public debt sustainability concerns.

Given that the two variables capturing the regulatory environment n and ε_D relate to financial openness and ownership structure, the model suggests that liberalizing the capital account and allowing for direct foreign participation in the government securities market would help reduce the level and the spread of T-bill and deposit rates.

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[29] Levy and Mántey (2003) point to the ability of banks in financial systems characterized by oligopolistic structures to extract a risk-free margin by setting deposit rates below the rate on government securities.

B. Market Segmentation Model: Explaining high volatility of yields during 2006-07

The game-theoretic framework below formalizes the notion of segmented markets discussed above and seeks to explains the apparent breakdown in the negative correlation between lagged yields and bid-cover ratios and increasing volatility in T-bill yields since late-2005. The model features three players: the BoT (the T-bill auctioneer), on the one hand, and 'naïve' investors and 'colluding banks' (the buyers) on the other. The bidding behavior of these groups is detailed below. Broadly, the naïve investors (comprising less sophisticated investors such as pension funds and smaller banks) are cast as backward-looking and trusting of BoT's announced issuance strategy; while the colluding banks (constituting of foreign and foreign-controlled banks) are cast as forward-looking and anticipatory of BoT's actual (as opposed to announced) issuance strategy.

Definitions and assumptions

In what follows, the term *bank* refers to large foreign-owned or controlled banks (i.e., colluding banks as opposed to small domestic banks) and not to any bank.

B - total investable bank funds;
I_A - issuance amount announced by the BoT (advertised in advance of an auction);
I - actual issuance by the BoT;
β - the degree of 'naivety' of naïve investors, $\beta \in [0,1]$, ($\beta = 1$ implies perfect foresight);
N - amount bid by naïve investors, $N = \beta I + (1 - \beta) I_A$;
r_0 - banks' reservation yield (the opportunity cost);
r_H - highest bid that banks believe the BoT can accept (tolerance yield);[30]
r_M - 'market' or completely naïve bid – i.e., previous week or month average yield;
r_N - yield bid by naïve investors, $r_N = (1 - \beta) r_M + \beta (r_0 - \eta)$;
r_L - yield bid by banks to undercut r_N;
μ - margin that ensures that banks succeed in undercutting r_N ($r_L = r_N - \mu$);
η - margin that ensures that naïve investors succeed in undercutting r_0 ($r_N = r_0 - \eta$ if $\beta = 1$);

Colluding banks. Banks are identically sized, have perfect foresight about I, and collude on yields and amounts bid. As discussed earlier, collusion could be explicit or implicit due to the $B_i \leq I_A$ auction rule giving incentives for collusion-like behavior by each bank in the group.[31] Given perfect foresight about I, banks can always procure the funds (either from abroad, or the local money market) required to 'take' an auction, so that $B > I$. As a necessary condition for banks' participation in an auction, we assume that $r_0 < r_M < r_H$. Finally, if banks decide to participate in an auction, they only bid 'low' or 'high' – i.e., $r_L \succ r_N$ and $r_H \succ r_N$ (see Annex for the elimination of the center bid.).

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[30] Since late 2005, the marginal interest cost of liquidity paper has been borne by government (rather than the BoT), which could have contributed to market perceptions that the BoT's tolerance yield on T-bill issuance for liquidity mop-up operations was relatively high.

[31] However, to the extent that weekly auctions are equivalent to a repeated game setup, it is also not unreasonable to countenance an explicit collusive equilibrium.

Naïve investors. Comprising pension funds and retail investors, this group bids yields as a weighted average of r_M and r_0 and amounts as a weighted average of I and I_A, as specified above. That is, complete naivety implies the group only bids past realized market yields r_M and the amounts announced I_A; whereas perfect foresight implies they bid exactly the amounts issued ex post and take the whole auction by successfully undercutting the banks.

The banks' maximization problem

Colluding banks must choose between one of three strategies:

strategy	no bid	low bid yield, r_L	high bid yield, r_H
payoff	$r_0 B$	$r_0(B - I) + r_L I$	$r_0(B - (I - N)) + r_H(I - N)$

For banks to participate in an auction, bidding low or high must be preferred to no bidding.

$r_L \succ no\ bid$ if $r_0(B - I) + r_L I > r_0 B \implies$

$$\beta < \frac{r_M - r_0 - \mu}{r_M - r_0 + \eta} \equiv \beta * \tag{1}$$

$\beta *$ - the 'cut-off' level of naivety - partitions the strategy choice set into low bid and non-participation regions (see Annex for $\beta *$ properties).[32] For μ and η small relative to $r_M - r_0$, (1) can be written as:

$$\beta < 1 - \frac{\mu + \eta}{r_M - r_0} \equiv \beta * \tag{1'}$$

$r_H \succ no\ bid$ if $r_0(B - (I - N)) + r_H(I - N) > r_0 B \implies$

$$I > I_A \text{ for } \beta < 1 \tag{2}$$

(2) implies that, in the presence of naïve investors, banks have an incentive to bid high as opposed to not participating if they believe the issued amount will be higher than the announced one.

Together, the sufficient conditions for banks' participation (1) and (2) imply that colluding banks have no incentive to participate in an auction if they believe the issued amount will be less than announced and the naïve investors are not 'sufficiently' naïve.

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[32] (1) implies that for $0 < \beta * < 1$, $r_0 < r_M - \mu$ must hold – i.e., the banks' reservation yield should be sufficiently low relative to the market yield to allow undercutting even completely naïve investors.

If banks participate, they bid high ($r_H \succ r_L$) if

$$r_0\big(B-(I-N)\big)+r_H(I-N)>r_0(B-I)+r_L I \;\Rightarrow$$

$$I>\frac{(r_H-r_0)(1-\beta)}{(r_H-r_M)(1-\beta)+\beta\eta+\mu}I_A\equiv I* \tag{3}$$

$I*$ partitions the bidding strategy choice set between bidding low and bidding high. The $I*$ schedule is downward sloping in $I\times\beta$ space and can be concave or convex (see Annex for $I*$ properties).

The participation constraints (1) and (2) and the bidding strategy frontier (3) can be presented graphically as in Figure 15. Colluding banks bid high in the intersection of $I>I_A$ and $I>I*$ regions and bid low in the intersection of $I<I*$ and $\beta<\beta*$ regions. The intersection of $I<I_A$ and $\beta>\beta*$ is the non-participation region.[33]

Figure 15: Graphical Presentation of Banks' Bidding Strategies
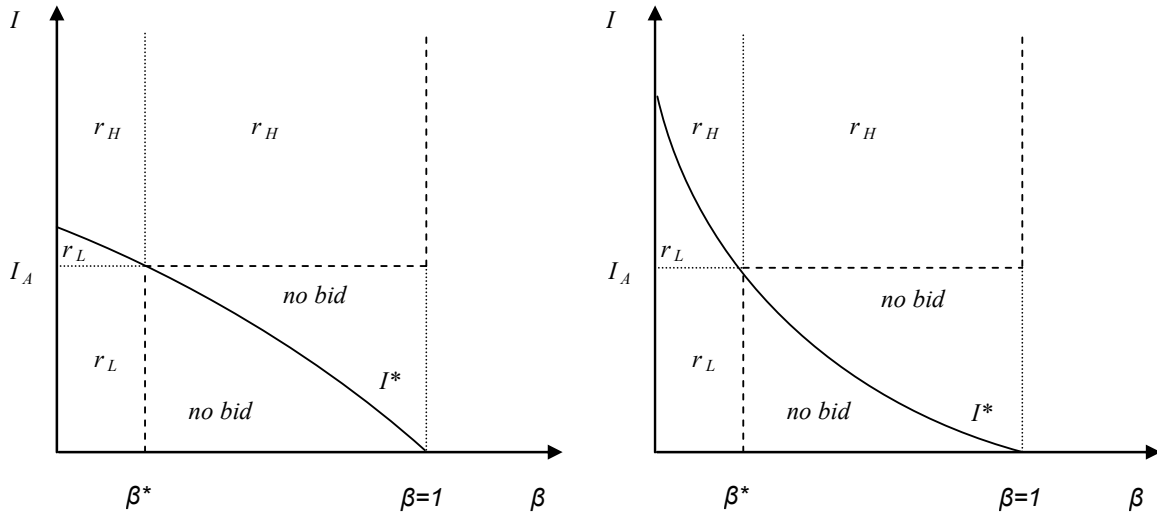
The equilibrium properties (see also Annex III) have the following implications:

- A high level of the tolerance yield r_H can render $I*$ concave (i.e., $\eta<r_H-r_M$) and would significantly reduce the banks' incentive to bid low – the vertical intercept, given by $I*|_{\beta=0}=\dfrac{r_H-r_0}{(r_H-r_M)+\mu}I_A$, shifts down. The practice of dipping deep into an oversubscribed auction (usually the 364-day paper) creates perceptions that the BoT will accept very high yields for the longest maturity (manifested in the observed

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[33] Empirical evidence in Tanzania supports the existence of the non-participation region: banks do not have failed auction bids, only naïve investors have unsuccessful auctions.

combination of high yields and a concentration of bid volumes around the 364-day paper at 'pressured' auctions), prompting the banks to bid high yield.

- Higher 'market' (realized) or backward-indexed yield r_M increases scope for banks to undercut naïve investors by bidding low whereas in the next cycle r_M is lower and the banks' incentives to bid high are greater, which generates volatility in yields.

- Announcing higher amounts I_A ex-ante, even if the actual ex-post issuance is lower, and never exceeding the announced amounts, would increase the banks' incentive to bid low yields or not to participate in the auctions.

IV. CONCLUSIONS AND POLICY RECOMMENDATIONS

The odd behavior of T-bill yields in Tanzania in recent years could not be fully explained by changes in the stock of government securities or by inflation and exchange rate depreciation expectations. Using evidence from bid-level data, and supported by theoretical models of oligopolistic bidding and market segmentation, this paper argues that the observed increases in the level and volatility of T-bill yields were likely to have been driven, respectively, by (i) strategic bidding behavior by large commercial banks exploiting their dominant position in the market (2002-05) and (ii) the emergence, thereafter, of a sharp segmentation of the T-bill market between sophisticated financial market players (foreign-controlled banks) and a less-experienced group of investors (domestic pension funds and small banks).

An important policy recommendation that emerges from the game-theoretic market segmentation framework is that public debt managers should avoid micro-managing T-bill auctions by issuing amounts in excess of those offered or by dipping into oversubscribed segments of the yield curve, as such practices seriously disadvantage the less-sophisticated but more competitive investors vis-à-vis the more sophisticated (and potentially collusive) players. The paper shows that, contrary to the prevailing concern among many African central banks that the risk of auction manipulation would increase with the predictability of the auctioneer's issuance strategy, increasing transparency and adhering to the announced amounts would help crowd in naïve but aggressive bidders and reduce the market power of potentially collusive investors.

Specifically, the following general recommendations can help reduce the market power of a few large banks in shallow/segmented government securities markets in LICs:

- Introducing a narrow range for issuance amounts in advance of an auction to help strike a balance between retaining some issuance flexibility, especially until repo operations are fully activated, and ensuring a level information-field for investors, particularly the relatively less-sophisticated ones who are less able to anticipate actual issue size ex ante;

- Avoiding deviations from the announced maturity distribution of T-bills by dipping into over-subscribed maturities. This would prevent the widening of the spread between the lowest and highest successful yield bid for the oversubscribed paper, thereby inducing heavier bidding in that maturity at subsequent auctions;

- Spreading bunchy rollovers over longer periods, reducing reliance on short-term paper for liquidity management and channeling government financing needs through longer-term bonds. The separation, to the extent possible, of instruments used for monetary policy from those used for debt management could help inform investors about the purpose of a particular debt operation and ensure proper signaling;
- Allowing more exchange rate flexibility through greater reliance on foreign exchange sales as a sterilization tool;
- Gradually liberalizing the capital account by granting direct primary market access to foreign investors to broaden the investor base and thus boost competition;
- Encouraging retail investor participation in the primary market by channeling the bids through financial institutions and adequately capitalized brokers, and by allowing individuals to participate in the auctions on a noncompetitive basis.

In the case of Tanzania, the steps taken by the BoT in recent months to improve liquidity management and to strengthen competition and transparency in the T-bill market in line with the above recommendations have brought a marked decline in T-bill yields, from 17 percent at end-June 2007 to 12 percent at end-December 2007.

ANNEX I: TECHNICAL ASPECTS OF T-BILL AUCTION SYSTEM IN TANZANIA

The Bank of Tanzania issues four T-bill maturities (35, 91, 182 and 364 days) and four T-bond maturities (2, 5, 7 and 10 years), the latter exclusively on behalf of the central government. The 182- and 364-day T-bills are used for both liquidity and financing purposes, although the tender sizes are combined with the aim of avoiding market segmentation. The 35- and 91-day T-bills are used exclusively for liquidity operations.

The auction is managed by the BoT on behalf of the government, and is held each Wednesday, on a discriminatory competitive bidding basis. Each Friday, the BoT sends an announcement of the planned offer sizes of T-bills, by maturity, to newspapers. These are published on Mondays. Banks must submit bids by 11 AM Wednesday by completing a simple paper bid form, and physically depositing them in the designated boxes at BoT Headquarters. All bids are then assigned numbers (amount, bid, code number), to prevent bias in the selection process. The BoT then selects the successful bidders, and enters the name of these bidders into their computer system, processes these, and produces an auction summary, which is published.

The BoT uses a discriminatory competitive bidding system, in which it selects the highest prices first, and then moves to lower bids until the desired amount is tendered. Bidders can have multiple bids, and are locked into the transaction if selected. Provided all conditions are met, a single bidder can take the entire amount offered (i.e., issue allocations are limited by the tender size). Offer sizes are broadly determined by the Monetary Policy Committee, which meets monthly. However, the BoT staff can deviate in reaction to, e.g., unexpected fluctuations in government spending. The BoT often accepts bid sizes above or below the offer size for each maturity. In deviating, it typically seeks to lower weighted average yields for maturities (e.g., it might sell more 35-day paper if bids are particularly strong, and ease off on 365-day paper if bids there are weak). Offer sizes and results are published before and after the auction, respectively. To buyers, there is no legal distinction between T-bills for liquidity and financing, though the market knows that 35- and 91-day paper is typically (though not always) for liquidity purposes. All T-bills are government obligations.

ANNEX II: QUANTITY-BASED BIDDING IN DISCRIMINATORY PRICE AUCTIONS

Illustration of quantity-based bidding in Tanzania's T-bill auctions
(Three equi-sized investors bid for a Tsh. 50 billion auction given the previous week's clearing yield of 7%)

Scenario A: Each of the three investors bids Tsh. 30 billion, split equally into three yield bands around 7%

	Bids received			Successful bids (auction size = Tsh 50 bn)	
Investor	Yield bid	Amount bid (Tsh billion)	Investor	Bid bands	Amount bid (Tsh billion)
A	5.0%	10.0	A	5.0%	10.0
A	7.0%	10.0	B	5.0%	10.0
A	9.0%	10.0	C	5.0%	10.0
B	5.0%	10.0	A	7.0%	6.7
B	7.0%	10.0	B	7.0%	6.7
B	9.0%	10.0	C	7.0%	6.7
C	5.0%	10.0			
C	7.0%	10.0			
C	9.0%	10.0			
Total amount tendered =		**90.0**	**Total amount auctioned =**		**50.0**
Weighted average yield bid =		**7.0%**	**Weighted average yield =**		**5.8%**

Scenario B: Each of the three investors bids Tsh. 20 billion, split equally into three yield bands around 7%

	Bids received			Successful bids (auction size = Tsh 50 bn)	
Investor	Yield bid	Amount bid (Tsh billion)	Investor	Bid bands	Amount bid (Tsh billion)
A	5.0%	6.7	A	5.0%	6.7
A	7.0%	6.7	B	5.0%	6.7
A	9.0%	6.7	C	5.0%	6.7
B	5.0%	6.7	A	7.0%	6.7
B	7.0%	6.7	B	7.0%	6.7
B	9.0%	6.7	C	7.0%	6.7
C	5.0%	6.7	A	9.0%	3.3
C	7.0%	6.7	B	9.0%	3.3
C	9.0%	6.7	C	9.0%	3.3
Total amount tendered =		**60.0**	**Total amount auctioned =**		**50.0**
Weighted average yield bid =		**7.0%**	**Weighted average yield =**		**7.0%**

ANNEX III: RULING OUT THE 'CENTER' STRATEGY FOR SOPHISTICATED INVESTORS

Bidding r_L is strictly preferred to bidding r_N if

$$r_0(B-I) + r_L I > r_0\left(B - \frac{B}{B+N}I\right) + r_N \frac{B}{B+N}I$$

where $\dfrac{B}{B+N}$ is a prorated auction issue allocation equal to the banks' share of bids in total. The condition holds if

$$\frac{\mu}{r_N - r_0} < \frac{N}{N+B} \quad \text{or} \quad \frac{\mu}{(1-\beta)(r_M - r_0) - \beta\eta} < \frac{N}{N+B} \quad \text{which is true for the plausible range of}$$

behavioral parameters and those empirically observed in Tanzania.

ANNEX IV: KEY EQUILIBRIUM PROPERTIES OF THE MARKET SEGMENTATION MODEL

Properties of $\beta*$

$\beta*$ is increasing in r_M and decreasing in r_0, μ, and η:

$$\frac{\partial \beta*}{\partial r_M} = \frac{\mu + \eta}{(r_M - r_0 + \eta)^2} > 0; \quad \frac{\partial \beta*}{\partial r_0} = -\frac{\mu + \eta}{(r_M - r_0 + \eta)^2} < 0$$

$$\frac{\partial \beta*}{\partial \mu} = -\frac{1}{r_M - r_0 + \eta} < 0; \quad \frac{\partial \beta*}{\partial \eta} = -\frac{r_M - r_0 - \mu}{(r_M - r_0 + \eta)^2} < 0$$

Properties of $I*$ in $I \times \beta$ space:

Intercepts: $\quad I*|_{\beta=0} = \dfrac{r_H - r_0}{(r_H - r_M) + \mu} I_A > I_A; \quad I*|_{\beta=\beta*} = I_A; \quad I*|_{\beta=1} = 0$

$$\frac{\partial I*|_{\beta=0}}{\partial r_H} = \frac{\mu + r_0 - r_M}{(r_H - r_M + \mu)^2} I_A < 0; \quad \frac{\partial I*}{\partial I_A} \frac{(r_H - r_0)(1-\beta)}{(r_H - r_M)(1-\beta) + \beta\eta + \mu} > 0$$

Slope: $\quad \dfrac{\partial I*}{\partial \beta} = -\dfrac{(\mu + \delta)(r_H - r_0)}{((r_H - r_M)(1-\beta) + \beta\eta + \mu)^2} I_A < 0$

Convexity: $\quad \dfrac{\partial\left(\dfrac{\partial I*}{\partial \beta}\right)}{\partial \beta} = \dfrac{2(\mu + \eta)(r_H - r_0)}{((r_H - r_M)(1-\beta) + \beta\eta + \mu)^3}(\eta - (r_H - r_M))I_A \Rightarrow$

convex if $\eta > r_H - r_M$ ($I*_{\beta\beta} > 0$), high vertical intercept,
concave if $\eta < r_H - r_M$ ($I*_{\beta\beta} < 0$), low vertical intercept.

Properties of the equilibrium

Given the properties of β^* and I^* derived above, the impact of changes in model parameters on the banks' incentive to participate and bid low yields – which is the BoT's desired outcome – can be summarized in the following table:

Parameter change	I^* vertical intercept	β^* horizontal shift	Incentive to bid r_L
$\mu \uparrow$	$\downarrow$	$\leftarrow$	$\downarrow$
$\eta \uparrow$	$\updownarrow$ (no change)	$\leftarrow$	$\downarrow$
$r_0 \uparrow$	$\downarrow$	$\leftarrow$	$\downarrow$
$r_M \uparrow$	$\uparrow$	$\rightarrow$	$\uparrow$
$r_H \uparrow$	$\downarrow$	$\leftrightarrow$ (no change)	$\downarrow$
$I_A \uparrow$	$\uparrow$	$\leftrightarrow$ (no change)	$\uparrow$

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