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Profitability and Pricing in Treasury Bill Auctions: Evidence from Pakistan

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Behaviour in the first three years of auctions for Pakistani treasury bills is studied. Bidding strategies rapidly converged to a consistent pattern after the auctions started in 1991. Factors that influenced the expected profitability of auction participation are identified. Auction participation was on average low and did not differ between types of bidders. Prices bids are found to reflect both 'buy and sell' and 'buy and hold' strategies, and were affected by risk considerations and bidder-specific variables. The Pakistani experience suggests the robustness of auctions as a market-based allocation mechanism, and their value in public debt management.

I. INTRODUCTION

Auctions represent a paradigmatic example of a market-based mechanism for the allocation of resources, albeit one characterised by asymmetric information and imperfect competition, and they have therefore long attracted the attention of economists.[1] In monetary terms, some of the most important auctions are those for government securities, which have now become common not only in the industrialised countries, but also in developing and transition countries as diverse as Jordan, the Czech Republic, Kenya, Mexico, and of course Pakistan. One aim of the present paper is to provide evidence on the functioning of a system of government securities auctions, in particular those that have recently been established in developing countries.

For Pakistan the introduction of a regular series of treasury bill auctions was part of a wide-ranging programme of financial sector liberalisation, and a move away from traditional, non-transparent means of government debt management towards a

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[1]Milgrom (1989) provides a useful survey. Bikhchandani and Huang (1993); Bartolini and Cottarelli (1994) and Das and Sundaram (1996) review the application of auction theory to government securities markets. Cammack (1979); Spindt and Stolz (1992); Umlauf (1993) and Simon (1994) are empirical studies of treasury bill markets.

market-based approach. The other main aim of this paper is to assess whether the auctions worked well for Pakistan, or whether they raised the cost of government borrowing unnecessarily or otherwise functioned unsatisfactorily.

After this introduction, the second section provides background on Pakistan's financial sector reform programme that started in the early 1990s, and the institutional arrangements for the treasury bill auctions. The third section describes the data set and presents some stylised facts about the evolution of the auctions. In Section Four, the profitability of participating in the auctions is estimated so as to establish the average cost to the government of conducting the auctions, and profitability is compared across bidders to detect evidence of abnormal returns. Profitability rates are then related to the explanatory variables suggested by the auction theory. The fifth section looks at the average prices bid and presents an attempt to identify their determinants, before the last section concludes.

II. DEVELOPMENT OF THE GOVERNMENT SECURITIES MARKET IN PAKISTAN

Financial Sector Reform in Pakistan[2]

For most of the period since independence, the Pakistani financial system has been subject to direction and control by government. All commercial banks in Pakistan were nationalised in 1974, and a system was instituted to channel funding to priority areas of development at controlled interest rates. Treasury bills were available, but they were sold on tap at a fixed interest rate. By the mid-1980s it was increasingly felt that incentives for saving (and for the remittance of savings from the large Pakistani community abroad) were inadequate, and that resources were not being allocated to the most productive uses. In addition, the traditional approach to public debt management was placed under increasing strain by the government's rising need for domestic financing.[3] In response, a programme of domestic financial sector liberalisation was launched in 1990–91.[4] The establishment of private banks was permitted in 1990, foreign banks were allowed to engage in more domestic business, and over time two state-owned banks were privatised. Interest rates were liberalised and credit ceilings dismantled.

In the area of public debt management, a major step was the initiation of a regular series of auctions of government securities: starting in February-March 1991,

[2]Khan and Aftab (1994) and Ul Haque (1997) provide a more extensive overview of the financial sector in Pakistan and its reform over the past decade.

[3]Total federal government debt had increased from 61 percent of GDP in 1985 to 74 percent of GDP in 1990, and domestic government debt rose from 31 percent of GDP to 42 percent of GDP. By 1990, debt servicing absorbed 39 percent of all government expenditure (*State Bank of Pakistan, Annual Report*, various issues).

[4]Liberalisation of the external capital account transactions moved more slowly, and in subsequent years was partially reversed.

the government began auctioning 6-month bills (the focus of attention in this study), and bonds with maturities of between 3 and 10 years. To promote demand for and secondary market trading in the new securities, the issuing of securities on tap and domestic bearer bonds was discontinued (although foreign currency bonds and bearer certificates were introduced), institutional investment in savings schemes was limited, and the State Bank of Pakistan (SBP) raised its rediscount rate on treasury bills to 10 percent. The liquid asset requirement, however, was retained. At a technical level, the new securities were registered in an electronic book entry system to facilitate trading. The SBP, which acted as the government agent in running the auctions, designated approximately sixty primary dealers from among the commercial banks and other financial institutions, who would bid at the auctions for domestic securities either on their own behalf or on behalf of clients, and who would subsequently trade in securities with each other and distribute them at a retail level. [5] Since 1991, these market-based instruments have become the major form of domestic government debt.[6]

Organisation of the Treasury Bill Auctions

The auctions of six-month treasury bill were conducted according to procedures in most respects, similar to those used in other countries but with some peculiarities. The auctions, which were held roughly every two weeks, were announced approximately one week in advance. Primary dealers and other bank and non-bank financial institutions were allowed to submit any number of sealed price-quantity bids on their own behalf or on behalf of clients. All auctions were conducted on a discriminatory price basis, so each bid was formulated in the expectation that, if accepted, the price bid would be that paid. After the deadline for bid submission, the bids were opened in the presence of the bidders; this rather unusual practice allowed all participants to know every bid by bidder.[7] The Ministry of Finance would decide on the cut-off price after seeing the bids; although notionally the size of the auction issue was pre-announced, in practice the cut-off price seems to have been the main decision variable and the amount allocated bore little relation to the pre-announced size. The setting of the cut-off price was influenced by a number of factors, of which debt service costs and the need for funding were most prominent. On a number of occasions the authorities decided to reject all bids, in part because they felt the bids were unreasonably low. This sentiment was expressed by Mr Mohammad Ilyas, Director of the Securities Department, SBP, who stated that

> "Out of 48 treasury bill auctions held up to 1st December, 1992 the Government had to reject all bids in 6 auctions only due to the fact that

[5]Carracedo and Dattels (1997) describe the new debt management system in detail.

[6]By 1993 treasury bonds and bills constituted one half of domestic federal government debt outstanding, excluding that to the SBP.

[7]The publication of bids made possible the collection of the data set used in this study.

> the bidders had quoted much lower prices which were not compatible with the market conditions".
>
> (*Journal of the Institute of Bankers in Pakistan*, 1994).

The extra degree of uncertainty created by the authorities' inability or unwillingness to pre-commit to selling a fixed quantity of bills constitutes a major departure from 'standard' practice in treasury bill auctions. Bidders were aware of this uncertainty (in addition to uncertainty about the aggregate bid schedule) and presumably took it into account when formulating their bidding strategies.

One or two days after the deadline for bid submission, the auction results would be communicated to the participants, and trading in the new bills would begin on a 'when-issued' basis.[8] Settlement would take place three or four days after the bids were submitted, and the when-issued trades would settle at the same time. Thereafter, the newly issued or 'on the run' bills would trade normally in the secondary market until the next auction. The participants in the secondary market were essentially the same institutions that participated in the auctions.

III. SAMPLE CHARACTERISTICS

Data Set and Definitions

Data were obtained on bidding behaviour and outcomes in the first 84 auctions of six-month treasury bills, covering a period from February 1991 to May 1994. The core of the sample is formed by observations of the price-quantity pairs that constituted the bids, each identified by bidder and by auction. After the deletion of a small number of outliers, which mostly seemed to reflect recording errors,[9] the data set comprised 6506 observations. Data on the cut-off price (designated *CO*), the maturity of each bill issue (which varied slightly around a mode of 183 days), and the dates of bid submission and results announcement were also available.[10] All prices were annualised (harmonising the maturities at 365 days), and logarithms taken.[11] Then means were estimated by auction and by bidder in each auction; below, in examining the prices bid, attention focuses on the weighted mean of the annualised log prices bid by each bidder in each auction (*WMP*). In addition, the standard errors of the prices bid, both by auction and by bidder by auction, were calculated as measures of bid dispersion. Also calculated were the total volume bid, the volume of winning bids, the total value of bids and winning bids for individual

[8]There does not seem to have been significant 'when-issued' trading before the deadline, as there is, for example, in the U.S. treasury bill market.

[9]In the first auction one bidder submitted two very low-priced bids, reportedly because an annualised discount factor had been applied by mistake.

[10]For auctions where all bids were rejected, a notional cut-off prices is defined at a level marginally above that of the highest bid received.

[11]Log prices are multiplied by 100 in order to increase the number of significant digits.

bidders (all in levels and in logarithms), the number of participating bidders and successful bidders, and the number of bids.

The data on bidding behaviour were complemented by those on secondary market prices. In particular, daily data were obtained on both the bid and offer price for treasury bills quoted in the Karachi interbank market for the period beginning with the twenty-fifth auction, by which time reportedly the secondary market in bills had become fairly liquid. The quotes, which were recorded in the course of the morning when activity was the heaviest, apply to whatever bill is "on the run", that is, the most recently issued bill. Thus, the treasury bill offer price up to the morning before the deadline for submission of bids for an auction (designated as *TBOFF*(–1)) represents the price at which a potential bidder could buy bills from the previous issue; the treasury bill bid price on the day when auction results were announced (designated as *TBBID*(+1)) represents the price at which a winning bidder could sell newly-auctioned bills in the when-issued market. The secondary market bid and offer prices were annualised, and logarithms taken. Other secondary market data included the overnight interbank interest rate, which may be taken as a measure of the cost of carry for commercial banks of holding treasury bills.

Characteristics of the Auctions and Bidding Behaviour

An examination of the data allows one to discern some of the main features of the auctions and bidding behaviour. The characteristics of the data, including the time-series properties, must also be reviewed in preparation for the econometric investigation.

Dispersion of Bid Prices and Volumes

A typical auction attracted scores of bids from perhaps two dozen bidders, for a total value of about Rupees (Rs) 10 billion, and on average about Rs 4 billion was sold in each auction. The shape of the bid schedule typically resembled the mirror-image of a cumulative distribution function, with a small value of bids at very high or low prices and most bids being clustered closely around the cut-off.

Figure 1 illustrates the evolution of prices over the course of all 84 auctions in the sample. The cut-off price, the weighted mean of the prices bid, and the range of bids are shown. Figure 2 shows the volume of bids and the volume of bids accepted. During the first five or six auctions, the range of prices bid was especially great, and the average price bid fluctuated around the cut-off. Presumably during this period participants were experimenting with their bidding strategies and learning to anticipate the strategies of each other and those of the authorities in setting the cut-off price. It is striking, however, that this learning period appears to have been quite short, and convergence to what proved to be typical bidding behaviour seems to have been achieved in about three months.

After this initial period, the average price bid was usually slightly below the eventual cut-off price, and the range of bids was typically equivalent to about 80

Figure 1 & 2

basis points. Much of the variation that did occur seems to have originated from the authorities, such as on those occasions when they rejected all bids (auctions 16, 19, 35, 45, 46 and 48). During a period from auction 45 through 62 the authorities allowed very little fluctuation in the cut-off price. As seen in Figure 1, that period saw a narrowing of the range of bids received, which also became more asymmetric, with a relatively long 'tail' of low bids and few bids significantly above the cut-off; presumably participants expected that any large deviation from the fixed cut-off price would be downwards. Figure 2 illustrates that the volume of bids received, and especially the amount allocated, decreased sharply during this period, which indicates that the cut-off price had been fixed at too high a level to sustain the previous level of funding.

Time-series Properties

The time-series properties of the series were reviewed. Most series displayed strong autocorrelation at lag 1, and often some correlation at lags 2 and 6. The serial correlation at lag 6, which corresponds to approximately a quarter year with bi-weekly auctions, may be the product of underlying seasonal influences in the Pakistani economy, notably the agricultural cycle and the quarterly payment of some taxes, including certain taxes on commercial banks.

The hypothesis of non-stationarity of the aggregate price series could not be rejected in augmented Dickey-Fuller tests. Changes in the cut-off price, the average price bid, and secondary market prices seem to be very persistent, as is common in financial market pricing.[12] The possibility of non-stationarity was taken into account in estimation by subtracting the previous cut-off price from all prices (all in logarithms); the hypothesis of non-stationarity could be rejected for the differenced series.[13]

IV. BIDDING PROFITABILITY

Definition of Profitability

The profitability of participating in an auction will be defined as the difference between the amount paid to obtain bills and their value in the secondary market a short time (specified below) after the auction. An examination of profitability should provide important indicators of how the auction market functions. First, a finding that profitability is relatively low and comparable in magnitude to that observed in other government securities auctions, such as those in industrialised countries, would

[12]The prices of the bills need not follow a random walk to be non-stationary or sufficiently close to non-stationary to present estimation issues in the limited sample available.

[13]The previous cut-off price should be well-known to market participants when they prepare their bids and in secondary market trading immediately before each auction. Individually differencing each series, including the average bid by bidder, would be problematic given the panel structure of the data set, especially because many bidders participated only sporadically.

be one indicator that the auction mechanism is working well and is not in itself adding significantly to the government's funding costs. Second, differences in the profitability rates obtained by different bidders can provide evidence on the degree of competition in the auctions, and whether or not some bidder or groups of bidders have monopoly power and are bidding relatively aggressively. Third, hypotheses derived from auction theory might be testable by relating profitability to certain other features of the auctions and bidders.

The available data allowed the calculation of the realised profits and the profit rate obtained by each successful bidder from auction twenty-five onwards. Suppose that a certain bidder b in some auction a submits a schedule of n price-quantity pairs $\{(p_{ba1}, q_{ba1}), ..., (p_{ban}\ q_{ban})\}$, the realised cut-off price is c_a, and on the day following the auction the bid price for treasury bills in the when-issued market is $bid_a(1)$ (all prices are in absolute terms). Then the bidder's profit PF_{1ba} merely from buying in the auction and selling immediately is

$$PF_{1ba} = bid_a(1) \sum_{p_{bai} \geq c_a} q_{bai} - \sum_{p_{bai} \geq c_a} p_{bai} q_{bai} . \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

This equation can usefully be rewritten as

$$PF_{1ba} = \left(bid_a(1) - c_a\right) \sum_{p_{bai} \geq c_a} q_{bai} - \sum_{p_{bai} \geq c_a} \left(p_{bai} - c_a\right) q_{bai}$$

which shows that the profit obtained in such a discriminatory price auction equals the profit in a comparable uniform-price auction (that is, the difference between the when-issued market price and the cut-off price, multiplied by the amount won), less the value of the 'upper tail' of bids that exceed the cut-off price. The profit rate will be defined as the ratio of profits to the total value won, or

$$PFR_{1ba} = \frac{bid_a(1) \sum_{p_{bai} \geq c_a} q_{bai} - \sum_{p_{bai} \geq c_a} p_{bai} q_{bai}}{\sum_{p_{bai} \geq c_a} p_{bai} q_{bai}} . \quad \ldots \quad \ldots \quad (2)$$

It may be unreasonable to assume in the context of the early development of secondary trading in Pakistani government securities that a significant participant in the auction could sell all the bills he had won on a single day in the when-issued market without drastically depressing the price. As a more moderate alternative, profits and profit rates were calculated assuming that each bidder sold the bills won in equal tranches in the course of the five days following the auction. On the first two of these days, trading would have been conducted on a when-issued basis, so there is no cost of carry, but cost of carry needs to be deducted from profits on the following three days; the offer rate on interbank loans was used as a proxy for the cost of carry. Thus, if the daily interbank rate on day t is denoted by $i(t)$, the

alternative measure of profits PF_{2ba} is defined as PF_{1ba} in Equation (1) above, but with $bid_a(1)$ replaced by

$$\frac{1}{5}\left[bid_a(1) + bid_a(2) + \frac{bid_a(3)}{(1+i(3))} + \frac{bid_a(4)}{(1+i(3))(1+i(4))} + \frac{bid_a(5)}{(1+i(3))(1+i(4))(1+i(5))} \right],$$

and similarly an alternative rate of profitability PFR_{2ba} can be defined.

Mean Profit Rates

Estimates were made of the profits obtained by bidders in the 60 auctions for which the necessary secondary market information was available. Total profits defined by PF_{1ba} (that is, from buying and selling immediately in the when-issued market) amounted to Rs 302 million over these auctions (approximately US$10 million at the then prevailing exchange rate) on a total value of Rs 267,538 million bills sold (with a face value of Rs 283,896 million). The corresponding overall weighted average profit rate PFR_{1ba} was 11.27 basis points. The weighted mean profit rate obtained by selling during the five trading days following each auction (PFR_{2ba}) was 13.29 basis points. Thus, mean profitability of participating in the Pakistani treasury bill auctions during this period was significantly positive, so in that sense bid shading occurred, but the level of profitability seems to have been quite low.[14] Commercial banks do not seem to have made exceptionally large profits at the expense of government merely by participating in the auctions. The two measures of profitability move together closely (the correlation between the two measures of profitability by bank is 0.854), and both are quite variable (the unweighted standard deviation of PFR_{1ba} is 29.64). On numerous occasions profits were negative.

These profitability rates can be compared with an estimated rate of about 4 basis points estimated by Cammack (1979) in auctions for three-month U.S. treasury bills during the 1970s, and of about 1.5 basis points estimated by Spindt and Stolz (1993) for auctions during the 1980s. While Umlauf (1993) estimates profitability at about 1.6 basis points in discriminatory-price auctions for Mexican one-month bills, Simon (1994) finds that the profitability of participating in auctions for longer maturity U.S. government bonds and following a 'buy and sell' strategy can reach about 1 basis point.[15] Thus, even after allowing for the longer maturity of the

[14]Another way to look at the issue of bid shading is to consider that, if the same face value of bills had been sold in a uniform price auction, the average price bid would have had to be 13.52 basis points higher for the same revenue to have been obtained. Bolten (1973) estimates that if uniform pricing were introduced into the U.S. Treasury bill auctions, revenue would be maintained if the quantity of bills demand increased by 1 percent.

[15]Feldman and Reinhart (1995) find that in IMF gold sales during the 1970s, the mean winning price was 12 basis points below the secondary market price when discriminatory pricing was used.

Pakistani bills, the observed profitability of auction participation in Pakistan was rather greater than the rates observed in the primary market for U.S. government securities. The latter market, however, is very deep and supported by an extremely liquid and sophisticated secondary market. These structural differences are illustrated by the fact that the range of bids in the U.S. primary market and bid-ask spreads in the U.S. secondary market are about an order of magnitude smaller than those typical of Pakistan during this period. Furthermore, the availability in the U.S. of when-issued trading before the auction may significantly reduce the risk of participation [Viswanathan and Wang (1999)]. It presents an interesting model of a treasury bill auction market with when-issued trading. Hence, the higher rate of profitability obtained by auction participants in Pakistan may largely reflect the greater risks they face.

The weighted mean profit rates for each bank were estimated, and the equality of each bank's profitability with the weighted average of all other banks was tested [the results are available in Hardy (2000)]. Tests were also performed to compare profitability between various groups of bidders, namely, foreign versus domestic banks, and privately-owned versus public. All the test results suggest that profitability did not differ systematically between most bidders, and only very few individual banks earned significantly more or less than the remainder. Data on profitability give no indication of collusion between any sub-set of bidders. However, two publicly-owned banks, including the bank that bid and won the greatest volume of bills, did achieve significantly lower rates of profitability. The relatively poor performance of the largest bidder can be attributed to a number of factors: it may be that, as a publicly-owned institution, its management made less effort to maximise profits or felt itself under pressure to hold down the government's borrowing costs, and therefore bid less aggressively. However, another plausible explanation is that the bank was hampered by its very size, as could occur if it had to maintain an inventory of bills in order to meet retail demand or to fulfil its liquid asset requirement, and due to the thinness of the secondary market it had to obtain a large volume in the primary market even at a relatively high price. Possibly, if this large bank ever acquired surplus bills in the auctions, its attempts to dispose of them would depress the secondary market price and thus its profits.

Profitability and Auction Theory

Further insights can be obtained by relating realised profitability to features of the individual auctions and the bidders' behaviour. The search for such relationships and their interpretation needs to be informed by auction theory, and indeed it would be desirable to test models of bidding behaviour. However, no comprehensive theoretical treatment is available of multiple-unit, multiple-bid repeated auctions with a resale market, such as treasury bill auctions. In the case of the auctions for Pakistani treasury bills, the uncertainty over the amount to be sold presents a further

complication. Hence, any hypotheses to be tested can have at best an heuristic basis in theory.

A model of a multiple-unit, multiple-bid auction that seems to fit the Pakistan case relatively closely is provided by Nautz and Wolfstetter (1997). Each bidder is assumed to be sufficiently small so that it behaves as a price taker in the auction.[16] For each point along the bid schedule, the bidder's marginal expected payoff depends on the difference between the bidder's true valuation and the amount paid, and the probability of the marginal bid being accepted. The bidder therefore faces a trade-off: the bid schedule can be shaded downwards more to increase the payoff rate, but the quantity of bills the bidder can expect to win is thereby reduced. This trade-off leads even a risk-neutral bidder to shade its bid and earn positive profits; risk aversion reduces but does not eliminate bid shading.[17]

In the interpretation of the model used here, the payoff from winning may depend both on the post-auction secondary market price and other common or possibly bidder-specific factors (for example, meeting inventory needs or fulfilling a liquid asset requirement). If the secondary market demand for the bills shifts upwards, which is associated with an increase in the aggregate amount bid and the amount won, then at each possible cut-off price the trade-off between higher profits and the probability of a bid being accepted is unchanged. Hence, expected total profits are unaffected, but the rate of profitability decreases due to the increase in the volume sold. This reasoning also suggests that if a large volume of bills was sold in the previous auction, so that banks are holding a large stock of close substitute for the new bills to be auctioned, then profits should be lower. Among other factors common to all bidders, the expected cut-off price is clearly a potential determinant of profitability, but the relationship is ambiguous: an increase in the expected cut-off price decreases both the expected volume won and the ratio of winning bids to total bids, and so could either raise or lower the expected profitability rate.

An upward shift in the bidder-specific demand for bills, which leads a bidder to bid more for the same expected secondary market price, reduces its expected profits. A bidder that bought a large volume in a recent auction is likely to have relatively low demand for new bills, and should therefore make somewhat higher

[16]This model assumes a downward-sloping demand schedule for each bidder. This assumption may be tolerable in the case of the Pakistani treasury bill auctions, because bid-offer spreads in the secondary market tended to be quite large (on the order of 50 basis points in terms of annualised yields); if a bidder won a quantity of bills such that he would not sell at the secondary market bid price nor buy at the offer price, then the total payoff would depend just on the bidder's individual demand for bills.

[17]Some of the hypotheses presented here are consistent with other theories of auction behaviour, and in particular with auctions that give rise to the 'winner's curse', whereby on average the winner has an over-optimistic prior expectation of the object's value. To compensate for this risk, bids are shaded downwards, and generally expected profits are positive. Greater dispersion of opinion about the true value of the object being sold and the cut-off price should lead to greater bid shading. Bikhchandani and Huang (1989) set out a model of a multi-unit auction with a resale market, albeit with bids restricted to unit quantities, and show that in general bidders will shade their bids.

profits. An individual bank may also on occasion be eager to acquire at least a minimum quantity of bills, perhaps to meet inventory needs, and therefore present a relatively price-inelastic bid schedule. A large proportion of bids by such a bank is likely to be accepted, and profitability would be reduced. Banks may also differ on a sustained basis in how aggressively they bid and the average profits they make in the auctions, perhaps due to differences in risk aversion, the importance to them of retailing treasury bills, or managerial incentives; such persistent differences can be captured econometrically through the inclusion of fixed effects.

Considerations of risk are likely to be important determinants of bidding behaviour and the return on participating in the auction, and in general higher risk should be compensated by higher expected return, for a given degree of risk aversion. The most important sources of risk for bidders are uncertainty over the aggregate demand for bills, uncertainty over the cut-off price that the government will set, given aggregate demand, and covariance between returns on bills possibly acquired at the forthcoming auction and other assets in the bidder's portfolio. Assessments of risk are not directly observable, so for estimation purposes one needs proxies such as the dispersal of bids made by each bidder—and of all bids in an auction—and the variability of secondary market prices for bills in the days leading up to the auction.

Specification of Regressions on Profitability

The theoretical literature suggest certain relationships between expected profitability and the actual or expected value of other variables. Expectations are not observed, but under the assumption of rational expectations realised, the realisation of a variable should equal its expectation plus a white noise error term. The realisations can be used in estimation, provided that the 'errors in variables' are dealt with through the employment of instrumental variables. In this case, instrumental variables estimation is also advisable in order to remove statistical bias due to possible simultaneity between variables.[18] These considerations lead to the following specification to be used in estimation:

$$\begin{aligned} PFR_i = {} & \alpha_1 SDPBID + \alpha_2 SDTBOFF + \\ & \alpha_3 AV + \alpha_4 (AW/AV) + \alpha_5 AW(-1) + \alpha_6 V + \alpha_7 (W/V) + \alpha_8 W(-1) + \\ & \Sigma \alpha_{fb}(\text{fixed effects dummies}) + \alpha_{a28}(\text{auction 28 dummy}) + (\text{error terms}), \end{aligned}$$

for profitability measures $i = 1, 2$ achieved by bidder b in auction a.[19] The risk terms *SDPBID* is the standard deviation of the log price bid by bidder b in auction a, and *SDTBOFF* is the standard deviation of the secondary market log offer price

[18]For example, bidders may raise the quantity bid when they expect high profitability, and greater dispersion in a bank's bids in itself may reduce profitability in a discriminatory price auction unless offset by ex-ante bid shading.

[19]Subscripts are dropped where there is no chance of ambiguity.

for treasury bills during the five market days preceding auction *a*. The levels of auction-wide and bidder-specific demand are captured by *AV* and *V*, respectively the log volume bid in auction *a* by all bidders together and by bidder *b* alone. The ratio of winning to total bids for all bidders (*AW/AV*) is meant to capture aggregate supply effects.[20] The equivalent ratio for bidder *b* (*W/V*) could capture other bidder-specific effects.[21] Also possibly relevant are *AW*(–1), the log volume of winning bids in the previous auction, and *W*(–1), the log volume won by *b* in the most recent auction in which he participated. The fixed effects dummy for each bidder *b* takes the value of 1 in observations relating to *b* and zero otherwise. The dummy for auction 28, which takes the value of 1 for observations from auction 28 and zero otherwise, is included to capture the (unexplained) circumstances which led to very high profits on that one occasion. The instruments used include up to six lags of the predetermined variables, plus the dummies, and comprise both bidder-specific and auction-wide variables.[22]

The principal sample used in estimation consists of all observations for which profitability could be calculated, excluding observations that on *a priori* grounds may be expected not to be representative, namely, (i) those from the period when the cut-off price was nearly constant, when also the quantity bid and participation declined sharply and prices bid converged to the cut-off; and (ii) single bids, that is, individual bids submitted mostly by very small and infrequent participants. After taking lags to construct instrumental variables, 509 observations are available in this restricted sample. Regressions were also run using other samples so as to judge the stability of the estimates.

Results of Regressions on Profitability

The results of regressing profitability on the various explanatory variables are presented in Table 1. Included besides the estimated coefficients and standard errors and some familiar statistics are the estimated generalised R^2 statistic, which Pesaran

[20]The total volume bid and the volume accepted are highly correlated with each other, but the level of the volume bid and the ratio of winning to total bids (the win ratio) are not. Therefore, including these variables in this form on the right-hand side of the equation to be estimated is econometrically advantageous.

[21]For example, two bidders may submit the same total volume of bids, but one may submit a more concave bid schedule with fewer high- and low-priced bids; under some circumstances the more concave bid-schedule could result in a higher proportion of bids accepted, or lower unit costs.

[22]The bidder-specific instruments included lags one and two of *WMP*, *SDPBID*, *V*, and *W*, and the dummy variables for all the banks that were awarded bills during these auctions. The auction-wide instruments include the first lag of *CO*, *AWMP*, *ASDPBID*, *AV*, *AW*, and *AW/AV*, and in addition lags two and six of *AWMP* and *AV*. The employment of longer lags of only two of the aggregate variables was motivated by the need for parsimony, given the relatively small number of auctions in the sample, and inspired by the results of Phillips and Hansen (1990), who suggest that the inclusion of numerous highly correlated instruments (especially when they are cointegrated) brings little gain in efficiency. Additional instruments included the dummy variable for auction 28, and known pre-determined variables *SDTBOFF* and *TBOFF*(–1).

Table 1

Determinants of Profit Rates

Dependent Variable	PRF_1	PRF_1	PRF_1	PRF_1	PRF_2
Estimation Method	IV	IV	IV	OLS	IV
	Fixed Effects	Fixed Effects	No Fixed Effects	Fixed Effects	Fixed Effects
SDPBID	58.488	46.439	24.187	1.321	38.924
	(20.040)**	(17.122)**	(10.850)*	(6.614)	(18.191)*
SDTBOFF	51.995	54.527	54.223	51.604	83.283
	(6.412)**	(5.950)**	(4.864)**	(4.793)**	(6.321)**
AV	21.168	20.890	13.429	13.127	19.272
	(4.090)**	(4.002)**	(1.934)**	(1.770)**	(4.252)**
AW/AV	–64.097	–37.583	–34.909	–52.591	–19.782
	(23.141)**	(8.135)**	(6.031)**	(4.060)**	(8.643)*
AW(–1)	–2.572	–2.942	–2.924	–2.498	–4.262
	(0.768)**	(0.692)**	(0.581)**	(0.571)**	(0.735)**
V	–20.219	–22.471	–2.722	–2.969	–20.387
	(6.927)**	(6.546)**	(1.458)+	(1.615)+	(6.954)**
W/V	31.721	–	–	–	–
	(25.843)	–	–	–	–
W(–1)	5.419	5.825	3.656	2.992	7.297
	(1.502)**	(1.436)**	(1.143)**	(1.036)**	(1.526)**
*AUC*28	69.219	72.294	68.321	54.572	37.923
	(12.055)**	(11.557)**	(8.965)**	7.186**	(12.278)**
Number of Observations	509	509	509	535	509
Mean of Dependent Variable	13.845	13.845	13.845	13.845	13.751
Standard Deviation of Dependent Variable	29.457	29.457	29.457	29.457	32.101
R^2	0.370	0.384	0.464	0.562	0.400
Generalised R^2	0.436	0.434	0.367	–	0.444
E'PZ*E	35101	32484	62303	–	31079

Standard errors are in parentheses. **: significant at 1 percent; *: significant at 5 percent; +: significant at 10 percent.

and Smith (1994) argues is a good measure of fit for an instrumental variables regression, and the term E'PZ'E, which is the instrumental variables equivalent of the sum of squared residuals.[23]

The regression results corroborate the hypotheses presented above. Looking at the principal specification for profitability measure 1 (Column 1), the risk terms both enter with positive and highly significant coefficients; it seems that bidders require compensation for both the risk manifest in the dispersion of their bids and that represented by fluctuations in the secondary market price of treasury bills. An increase in the total volume bid, that is, strong aggregate demand for bills, is associated with higher profits, and profits tend to be lower, the greater the proportion of this demand that is met (the supply effect). When a large volume of similar bills is outstanding, because a large volume was awarded in the previous auction, the reward to acquiring new bills is the less. Turning to the bidder-specific quantity terms, a bidder who submits a relatively large volume of bids tends to achieve low profitability, but the proportion of bids accepted has only a weak positive effect on profitability (this term is therefore dropped from subsequent specifications). The lagged volume won has a positive effect on profits, suggesting that a bidder holding a relatively large inventory of similar bills will bid more aggressively and earn higher profits on the bills that are in fact won. Results for profitability measure 2 (shown in Column 5) are similar.

The fixed effects are jointly significant.[24,25] Nonetheless, when they are excluded from the specification (see Column 3 of Table 1), most other estimated coefficients are not greatly affected; the most important change is that the coefficient on the individual volume term becomes much smaller absolutely, and less significant, and the estimated coefficients on the other bidder-specific explanatory are also lowered. Estimating the model by OLS generally reduces the magnitude and significance of the estimated coefficients, especially those on bidder-specific variables and those that are not predetermined, such as the dispersal and volume of bids. Results are robust to changes in the sample; results for regressions on the full sample including singleton bids and the period of a fixed cut-off price, and on a sample including only the last 22 auctions [available in Hardy (2000)], do not differ substantially from those presented here.

V. PRICES BID

The explanations presented and tested above for the measured profitability of participating in the auctions, which are formulated primarily in terms of quantities,

[23]Heteroskedasticity-consistent estimators of the standard errors [White (1980)] were calculated, but the significance of estimated parameters was not greatly affected when they were employed.

[24]The relevant test statistic is 9.756, which has an $F(43,457)$ distribution and is highly significantly different from zero.

[25]The regressions were run with the fixed effects replaced with dummy variables identifying groups of bidders, such as public sector banks, foreign banks, or small bidders. Almost all the estimated coefficients on these dummies were insignificantly different from zero.

suggest that profitability will depend on aggregate demand and supply conditions, and on idiosyncratic factors. These factors have also implications for the level of the prices bid, so that for example strong demand or anticipated limited supply for bills will tend to raise both profitability and prices bid. The interpretation of the results of the profitability regressions can be checked by examining the relationship between prices bid and the same explanatory variables.

This approach, however, needs to be complemented by a more general examination of the determinants of bidding behaviour. In particular, one may ask whether bidders determine their bid schedules in order to maximise profitability of buying in the auction and immediately thereafter 'marking to market' their positions, or whether they have other objectives, such as maximising returns over the longer term; the question is whether bidders are following a 'buy and sell' or a 'buy and hold' strategy. Under the 'buy and sell' strategy, prices bid should be determined by the expected secondary market price following the auction, the expected cut-off, and measures of risk (insofar as they are not already incorporated in prices). Under the 'buy and hold' strategy, prices bid should be determined by the expected cut-off price, the price of substitute assets in the bidders' investment portfolio, and risk measures. A third possibility is that bidder-specific factors determine the prices bid. The approach taken here to assessing the relative importance of the three explanations is to estimate the relationship of prices bid to, respectively, the expected secondary market price, the price of outstanding treasury bills issued in the most recent auction (which are the closest substitute for the bills to be issued), and the bidder-specific variables such as the individual quantity bid, in addition to the risk measures and the expected cut-off price. Note that, in the absence of rationing, price terms should capture the information relevant for the determination of bidding behaviour, and so one would expect that aggregate quantity variables would not be significant explanatory variables.

Bidders cannot know the cut-off price and the subsequent secondary market value of bills when they determine their bid schedules, but must base their bids on expectations, which are unobserved. For estimation purposes, the realised values of these variables can be used, provided that an instrumental variables technique is employed in estimation. The need for instrumental variables estimation is also motivated by the possible simultaneity between prices bid and certain candidate explanatory variables, such as the spread of bids.

With these motivations, the principal specification for the pricing of bids was chosen to take the form

$$
\begin{aligned}
WMP = {} & \beta_1 ASDPBID + \beta_2 SDTBOFF + \\
& \beta_3 TBBID(+1) + \beta_4 CO + \beta_5 TBOFF(-1) + \\
& \beta_6 V + \beta_7 (W/V) + \beta_8 W(-1) + \\
& \Sigma \beta_{fb}(\text{fixed effects dummies}) + \beta_{a28}(\text{auction 28 dummy}) + \\
& (\text{error terms}),
\end{aligned}
$$

where *WMP* is the weighted mean of the log annualised prices bid by bidder *b* in auction *a*. The risk terms are *SDTBOFF*, as before, and *ASDPBID*, which is the weighted standard deviation of all prices bid in auction *a*.[26] The term *TBBID*(+1) denotes the treasury bill bid price (how much one can sell a bill for) in the when-issued market on the day following auction *a*, *CO* is the cut-off price in the auction, and *TBOFF*(–1) is the treasury bill offer price (how much one must pay to acquire a bill issued in the previous auction) immediately before bids must be submitted. The bidder-specific terms (volume bid, winning ratio, past winning volume, and fixed effects) are the same as in the profitability regressions. Regressions were also performed including the other explanatory variables from the profitability regressions. The main sample is again that excluding singleton bids and the period of a stable cut-off price, but there are more observations (740 after construction of the instruments) because the average prices bids from unsuccessful bidders are also included. The instruments used are the same as in the profitability regressions.

Results are presented in Table 2. The first column shows the estimated coefficients from a regression of average prices bid just on the variables used to explain variations in profitability. The most prominent but perhaps unsurprising result is that bidders who can be expected to be awarded a high share of their bids relative to the average also bid relatively high prices. When a high aggregate volume is bid or when a low volume was sold in the previous auction, then average prices bid is higher, presumably because bidders anticipate a higher price in the subsequent secondary market. An individual bidder that bids for a large volume, or that won relatively little the last time it participated in an auction, also tends to bid higher, although these effects are not statistically significant. A high spread of bids, indicating more uncertainty about the auction outcome, is associated with lower prices, but the coefficient on the standard deviation of past secondary market prices enters with the wrong sign.

The inclusion of price terms improves the explanatory power of the regression considerably (Column 2), and eliminates the statistical significance of most quantity terms; the (expected) prices convey more information than the quantities. Of the quantity terms, only the win ratios and the individual volume bid were found to be significant; the standard deviation of prices bid by all bidders was found to be more significant than the equivalent measures for individual bidders.

The results of estimating a relatively parsimonious specification are shown in Column 3. Columns 4 and 5 show results obtained when the fixed effects are excluded, and when all bidder-specific terms are excluded. Several features stand out:

[26]Regressions were also run using the standard deviation of each bidder's prices bid, as in the profitability regressions; results were similar but significance levels tended to be somewhat lower.

Table 2

Determinants of the Average Price Bid

Dependent Variable	*WMP*	*WMP*	*WMP*	*WMP*	*WMP*	*WMP*
Estimation Method	IV Fixed Effects	IV Fixed Effects	IV Fixed Effects	IV No Fixed Effects	IV No fixed Effects	OLS Fixed Effects
TBBID(+1)	–	0.248	0.258	0.173	0.118	–0.015
		(0.105)*	(0.073)**	(0.514)**	(0.059)*	(0.022)
CO	–	0.312	0.200	0.192	0.160	0.382
		(0.175)+	0.095*	(0.070)**	(0.081)*	(0.038)**
TBOFF(–1)	–	0.201	0.225	0.243	0.308	0.254
		(0.079)*	(0.058)**	(0.035)**	(0.040)**	(0.026)**
SDTBOFF	0.414	–0.168	–0.127	–0.028	0.034	0.131
	(0.171)*	(0.001)	(0.095)	(0.070)	(0.081)	(0.054)*
ASDPBID	–	–0.704	–1.149	–0.821	–0.763	–0.451
		(0.480)	(0.178)**	(0.127)**	(0.147)**	(0.073)**
SDPBID	–0.679	–0.622	–	–	–	–
	(0.544)	(0.587)				
AV	0.258	0.005	–	–	–	–
	(0.113)*	(0.071)				
AW/AV	–4.120	–1.113	–	–	–	–
	(0.913)**	(0.484)*				
AW(–1)	–0.046	0.010	–	–	–	–
	(0.020)*	(0.011)				
V	0.203	–0.115	–0.133	–0.026	–	0.022
	(0.158)	(0.072)	(0.064)*	(0.011)*		(0.015)
W/V	3.593	1.311	–	–	–	–
	(0.779)**	(0.373)**				
(*W/V*)–(*AW/AV*)	–	–	1.517	1.104	–	0.759
			(0.367)**	(0.096)**		(0.040)**
W(–1)	–0.007	–0.001	–	–	–	–
	(0.009)	(0.004)				
*AUC*28	1.049	0.507	0.588	0.538	0.536	0.704
	(0.347)**	(0.187)**	(0.186)**	(0.145)**	(0.170)	(0.106)**
No. of Observations	740	740	740	740	740	764
Mean of Dependent Variable	0.021	0.021	0.021	0.021	0.021	0.021
Standard Deviation of Dependent Variable	0.476	0.476	0.476	0.476	0.476	0.476
R^2	0.323	0.591	0.545	0.580	0.364	0.649
Generalised R^2	0.347	0.457	0.455	0.407	0.321	–
E'PZ*E	19.128	0.735	1.021	9.126	23.474	–

Standard errors are in parentheses. **: significant at 1 percent; *: significant at 5 percent; +: significant at 10 percent.

- The estimated coefficients on all three price terms are significantly greater than zero and of similar magnitude. It would appear that bidding behaviour reflects a mixture of the 'buy and sell' and 'buy and hold' strategies.
- The coefficients on the risk measures enter with the anticipated negative sign and are significantly different from zero. Greater uncertainty over the auction outcome and the subsequent value of the bills seem to lower the prices bid.
- Bidder-specific factors are of importance, and the fixed effects are jointly significant.[27] The coefficient on the relative share of bids accepted, which can be thought of as capturing a range of idiosyncratic factors, is of considerable magnitude and highly significantly positive. The volume bid by an individual enters with a negative sign; bidding a higher quantity, and keeping the expected win ratio unchanged, involves submitting relatively many low-priced bids.[28]

Estimating the model by OLS (Column 6) has a marked effect on a number of parameter estimates. In particular, the coefficient on the future secondary market price becomes insignificant, the coefficients on the standard deviation of secondary market prices and the volume bid reverse sign, and the coefficients on the bid spread and the relative win ratio become much smaller in magnitude. The adoption of an instrumental variables technique to relate prices bid to expectations thus seems warranted. As were the regression results for the profitability equation, results are robust to changes in the sample [see Hardy (2000)].

VI. CONCLUSIONS

The examination of bidding behaviour during the first three years of Pakistani government treasury bills presented in this paper yields a number of findings.

- The typical pattern of bidding behaviour was established relatively quickly, after about five or six auctions. The secondary market became active over the first year of the auctions.
- The average profitability of participating in the auctions was positive (as one would expect from auction theory), but quite low in absolute terms and also when compared with the normal bid-ask spread in the secondary market. Profitability was on average higher than found in similar discriminatory-price auctions for government bills in other countries, but not unreasonably so given, in the case of Pakistan, the uncertainty over the

[27]The test statistic of 115.528 for the hypothesis that coefficients on all the fixed effects are zero, with an $F(47,684)$ distribution, is highly significant. When, alternately, dummy variables identifying groups of bidders were included, the estimated coefficients were insignificant.

[28]The individual volume bid enters the estimated profitability equation with a positive sign, but the relevant sample contains only the accepted bids, which are *ipso facto* relatively high.

quantity to be sold, the relative thinness of the secondary market, and the absence of when-issued trading before the auctions. Average profitability did not differ systematically across types of bidders, which, together with the large number of participants, suggests that collusion was not pervasive. In sum, as measured by profitability of bidding, the auctions do not seem to have been an expensive way to raise government financing.

- Again, in conformity with the predictions of auction theory, expected profitability was higher, and the average price bid was lower, the greater the risks faced by bidders. These risks, which find expression primarily in the dispersion of bids, include in particular the uncertainty surrounding the cut-off price that the government will select, and fluctuations in the level of demand for the new issue of bills.
- Profitability tended to be higher, the higher the aggregate demand for bills, as shown by the total amount bid; and lower, the greater the quantity of bills issued. Profitability was reduced when there was a large stock of similar bills outstanding in the market. These results suggest that bidding behaviour was inconsistent with the assumption that the value of the bills was strictly common to all bidders; bidding behaviour seems to have been influenced by considerations of desired inventory maintenance and the transaction costs of trading in the secondary market.
- Bidder-specific effects were significant. Notably, a bidder that submitted a relatively large volume of bids on average earned lower profits, but a bidder that held a relatively large stock of bills bid more aggressively and earned higher profits. These regularities again suggest that bidders were concerned to maintain a target quantity of bills in their portfolios.
- The average price bid in an auction was normally influenced in approximately equal measure by the expected post-auction secondary market price of the bills to be issued, and the secondary market price of old bills that obtained at the time the bids were formulated, in addition to the expected cut-off price. Thus, prices bid seemed to reflect a mixture of 'buy and sell' and 'buy and hold' strategies.

In conclusion, Pakistan seems to have been able to establish a successful primary market for treasury bills, and to develop an adequately liquid secondary market within the period considered here. The Pakistani experience gives credence to the effectiveness of auctions as a mechanism to determine a market-based price and allocation even under conditions of asymmetric market power and considerable uncertainty.

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