Rafi Eldor
Arison Business School, Interdisciplinary Center, Herzelia, Israel

Shmuel Hauser
Ben Gurion University and Rutgers University, Camden

Michael Kahn
Bank of Israel

Avraham Kamara
University of Washington

The Nontradability Premium of Derivatives Contracts*

We investigate nontradable and tradable identical Treasury derivatives. The nontradability premium is statistically and economically significant, and it covaries positively with interest rate volatility and relative tightness in the markets. Our data offer an almost-perfect laboratory to study the determinants of liquidity. The product of conditional interest rate volatility times the underlying bill's turnover is a better liquidity measure than the trading volume, amount outstanding, and turnover. A higher turnover is associated with a lower expected time for trading at a "desirable" price. The higher the volatility, the larger the marginal value of a reduction in the expected time to trade.

> Derivatives businesses are . . . like Hell . . . easy to enter and almost impossible to exit (Warren Buffett [2003, 13])

I. Introduction

The tradability of securities is an important determinant of their values and their use by financial institutions. The view that securities can be traded continuously and costlessly is a fundamental assumption underlying seminal asset pricing models (e.g., Black and Scholes 1973; Merton 1973). Yet the majority of

* We thank the Bank of Israel and the Tel Aviv Stock Exchange for providing the data. We thank an anonymous referee, Eric Zivot, seminar participants at Interdisciplinary Center Herzelia, Tel-Aviv University, the University of Washington, the Monetary Department of the Bank of Israel, the 2001 annual conference of the Multinational Finance Society, and the 11th Conference on the Theories and Practices of Securities and Financial Markets for helpful comments. R. Eldor thanks the Caesarea Edmond de Rothchild Center for Capital Markets for financial support. A. Kamara thanks the University of Washington's CFO Forum and Global Business Center for their financial support. Contact the corresponding author, Avraham Kamara, at kamara@u.washington.edu.

[*Journal of Business*, 2006, vol. 79, no. 4]

0021-9398/2006/7904-0014$10.00

derivatives contracts in the United States and the world consists of forward contracts and swaps.[1] A key characteristic of these derivatives is that many are very costly (sometimes impossible) to retrade before their expiration. The difficulty that financial institutions have liquidating assets and disengaging quickly in turbulent times in some financial markets (e.g. the Russian and Asian markets crisis of 1997–98) also illustrates the importance of tradability. There is, therefore, growing interest among academics, practitioners, exchanges, and regulators in the effects of nontradability and illiquidity on asset values and the functioning of financial markets.[2]

This article enhances our understanding of the value and determinants of nontradability. It investigates a unique sample of nontradable contracts for future delivery of Israeli Treasury bills, which have identical tradable (synthetic) contracts. Interest rate derivatives constituted more than 70% of the global over-the-counter derivatives market at the end of 2002 (Bank for International Settlements 2003).

Thus far, to our knowledge, the effects of nontradability on the valuation of interest rate derivatives have not been empirically investigated.[3] Nontradability can have significant implications for derivatives prices because they are derived using no-arbitrage pricing models.

An empirical study of a nontraded asset and its otherwise identical traded asset, however, has implications for the entire field of finance. The methodology of finance is the use of traded securities to price "twin" financial and real assets. The valuation methodology in corporate finance, for example, is to estimate the cash-flow characteristics of the project, find a twin traded security, and use the twin as the basis for valuing the project. That the project is typically nontraded is almost always ignored. Our results suggest that the

1. According to the International Swaps and Derivatives Association and the Bank for International Settlements, the global notional amount of financial over-the-counter derivatives at the end of 2002 was $142 trillion, including $102 trillion of interest rate derivatives (Bank for International Settlements 2003).

2. See, e.g., the American Finance Association's Presidential Address, by Maureen O'Hara (2003). Employee stock options and restricted stocks plans are another important group of nontradable assets. The Financial Accounting Standards Board (U.S.) and the International Accounting Standards Board (UK) have been studying how to value and account for nontradable employee stock options.

3. Brenner, Eldor, and Hauser's (2001) study of foreign currency options is the only empirical study of which we are aware on the effects of nontradability on derivative prices. The tradable and nontradable options in their study did not have the same maturity. As a result, they use the Black-Scholes (1973) model to estimate relative prices. An important advantage of our article, in addition to providing scarce evidence from another market, is that the tradable and nontradable contracts studied here are (otherwise) identical. Moreover, Brenner et al. (2001) do not study the determinants of the nontradability premium, which is one of the primary objectives of our article. Kamara (1988) and Grinblatt and Jegadeesh (1996) investigate the effects of liquidity differences on U.S. Treasury bill and Eurodollar futures and forwards. Kamara (1988) finds that greater liquidity causes Treasury bill futures yields to be significantly lower than implied forward yields, whereas Grinblatt and Jegadeesh (1996) find that liquidity differences do not have a significant effect on Eurodollar futures-forward spreads. As we discuss below, both studies suffer from the weakness that the spreads can be affected by other important factors in addition to liquidity.

differences between the equilibrium values of a nontraded asset and its twin traded security can be substantial. We also investigate the factors that affect these differences.

Existing empirical knowledge on the effects of nontradability on asset values is limited. This is because there are very few cases where actual market prices of a nontradable security and its traded twin are observed. Silber (1991) examines nontradable privately placed stocks, Boudoukh and Whitelaw (1993) study Japanese government securities, and Brenner et al. (2001) study nontradable foreign currency options.[4] We extend this set by examining Israeli interest rate securities and derivatives. As we advance below, the Israeli interest rate market offers a scarce opportunity with almost-perfect laboratory conditions.

The structure of the Israeli Treasury market supports the model of Boudoukh and Whitelaw (1993). They derive an economy in which it is optimal to issue two bonds with identical payoffs, but while one bond is tradable, the other is nontradable. They show that segmenting the markets along the dimension of tradability is the optimal way of discriminating between different types of investors (e.g., hedgers vs. traders) and extracting consumer surplus.

We define the nontradability premium as the difference between the yield on the nontradable derivative contract and the yield on the otherwise identical tradable contract. Buyers of nontradable contracts require an additional return to compensate for the cost of forgoing the option to trade. We find that the nontradability premium is statistically and economically significant. The mean nontradability premium (annualized, net of transactions costs) in January 1992–June 1997 on contracts for delivery, 3 months ahead, of 6-month bills is 38 basis points. The mean premium in July 1997–December 2002 on contracts for delivery, 3 months ahead, of 3-month bills is 31 basis points. Translating the premiums into differences in dollar income from holding the contracts to maturity, buyers of traded contracts could have increased their income in 1992–2002 by 3%, on average, by buying the nontradable contracts instead. In 10% of the cases they could have increased their income by more than 7%.

Longstaff's (1995) model of the option to trade advances that the nontradability premium is a positive function of price volatility and the time to expiration. Supporting Longstaff (1995), we also find that the nontradability premium covaries positively with interest rate volatility. The nontrading period in our sample is only 3 months, and Treasury bills are among the least volatile securities. This suggests that differences between the values of tradable and nontradable "twins" can be considerable.

While the nontradable asset is perfectly illiquid, the tradable contract is not perfectly liquid. The premium that investors are willing to pay to buy the tradable contract rather than the nontradable contract should increase as the

4. Longstaff has written theoretical studies (1995, 2001) on the effect of nontradability on optimal portfolio strategies and asset values.

tradable contract becomes more liquid. Consequently, investigating the relation between the yields on tradable and nontradable securities also enables us to study the determinants of the liquidity of the tradable asset.

There are many studies on the liquidity of U.S. Treasury securities. They include, for example, work by Kamara (1988, 1994), Amihud and Mendelson (1991), Simon (1991, 1994), Warga (1992), Daves and Ehrhardt (1993), Elton and Green (1998), Fleming (2002, 2003), Krishnamurthy (2002), Strebulaev (2002) and Goldreich, Hanke, and Nath (2003). The evidence regarding the effects of liquidity on Treasury yields is mixed. Kamara (1988, 1994), Amihud and Mendelson (1991), and Krishnamurthy (2002) find economically significant liquidity premiums, whereas Elton and Green (1998) and Fleming (2002) find that though liquidity is a significant determinant in relative yields, its role is much less than previously reported. Daves and Ehrhardt (1993) and Strebulaev (2002) find that liquidity effects are negligible or even nonexistent.[5]

Our study makes a unique contribution to the study of the effects of liquidity on the values of fixed income securities because our 1992–97 data allow us to overcome important shortcomings of earlier studies. First, Kamara (1988, 1997) finds that time variations in forward and relative spot Treasury yields in the United States contain premiums for the risk that short sellers will default.[6] In contrast, our sample of Israeli Treasury securities is unique in that the market for short selling was nonexistent in 1992–97. Consequently, counter-party risk of short positions should not affect the relative yields in our study. Second, relative prices of U.S. Treasury securities are affected by differential taxes, and the ability to arbitrage the tax effects is affected by liquidity considerations (e.g., Kamara 1994; Elton and Green 1998). Discerning their effect is challenging because they depend on when the seller originally purchased the security she is selling and whether it is selling at a

5. Krishnamurthy (2002) and Goldreich et al. (2003) study the behavior of liquidity premiums of on-the-run Treasury notes and bonds over the on-the-run cycle. The premiums decline over the cycle and almost disappear shortly before the next note or bond is issued. Longstaff (2000a) advances that even a small amount of security-specific liquidity variation in bond prices may eliminate any possibility of arbitrage. Consequently, bond markets are incomplete, and the various forms of the expectations hypothesis cannot be ruled out on theoretical grounds. Longstaff (2000b) shows that, in contrast to tests using rates on relatively less liquid Treasury bills, tests using rates on very liquid repos support the version of the expectations hypothesis in which term premiums are zero.

6. To buy or sell Treasury forward contracts in the United States, one has to buy and short sell Treasury securities with different maturities. Traders in these synthetic forward contracts face the risk that their counter-parties may default. Although Treasury securities are default free, short positions in Treasury securities, and hence long and short positions in synthetic forward contracts in Treasury securities, are not default free. In contrast, U.S. futures markets have a clearing association that serves as the guarantor of every contract and employs safeguards that virtually eliminate default risk. Kamara (1988) shows that spreads between implied forward Treasury bill rates and Treasury bill futures rates in the United States are positive and significantly positively related to measures of default risk, including the standard deviation of the change in spot rates. This implies that spreads between long-term and short-term U.S. Treasury bill yields contain default premiums. Kamara (1997) presents evidence that time variation in the spot U.S. Treasury term structure results from time variation in both nominal risk-free interest rates and forward default premiums.

discount or a premium; in addition, tax laws change frequently (see, e.g., Green and Ødegaard 1997). In contrast, as we discuss below, taxes should not affect the relative yields of the Israeli Treasury securities studied here (aside from at the end of the year). Third, unlike studies of liquidity differences in U.S. futures and forward interest rate contracts (e.g., Kamara 1988; Grinblatt and Jegadeesh 1996), where futures are marked-to-market daily but forwards are not marked-to-market, all the securities in our sample are guaranteed by the Bank of Israel and are not marked-to-market. Overcoming these shortcomings is important because economic theory suggests that the effects of liquidity risk, default risk, tax options, and marking-to-market on equilibrium-relative (spot, futures, and forward) interest rates are all functions of interest rate volatility. Moreover, the profitability of tax arbitrages and effects of default risk are related to the assets' liquidity.[7] The Israeli Treasury bill market in 1992–97 thus offers an almost-perfect laboratory, which is typically not possible in the United States, to isolate the effects of tradability and liquidity on the prices of fixed income securities and their derivatives.

Outside the U.S. Treasury market, there is a scarcity of research on this subject. Notable exceptions include Green and Rydqvist's (1997) study of Swedish government bonds, the Boudoukh and Whitelaw (1991, 1993) studies of the Japanese government bond market, and Gwilym, Trevino, and Thomas's (2002) study of the bid-ask spreads of international bonds in 2000. Our article helps fill the gap.

We find that the nontradability premium covaries positively with the product of the conditional interest rate volatility times the underlying bill's turnover. This liquidity measure is based on Garbade and Silber (1979), Lippman and McCall (1986), and Kamara (1994). A higher turnover of a security is associated with a lower expected time of being able to trade at a "desirable" price. The higher the volatility, the larger the marginal value of a reduction in the expected time required to trade at a desirable price. We find that the product of volatility times turnover is a better liquidity measure than the trading volume, amount outstanding, and turnover (alone). This suggests that interest rate volatility and expected time to transact are not independent attributes of liquidity. Rather, liquidity is an increasing function of the interest rate volatility times the expected time to transact.

We also find evidence supporting the predictions of auction theory, which predicts a negative relation between an auction's excess demand and yield, and, in particular, evidence supporting the predictions of Boudoukh and Whitelaw (1993) regarding the effects of relative excess demands on the nontrad-

7. Longstaff (2004) finds that periods of increased default risk are also characterized by flights to more-liquid U.S. Treasury securities. Duffie (1996) and Jordan and Jordan (1997) find that relative U.S. Treasury yields are affected by securities that are used as "special" collateral in repurchase agreements and that this can affect their liquidity. The difficulty of separating liquidity and credit risk premiums is also a crucial problem facing researchers of corporate bonds and credit derivatives. For example, Delianedis and Geske (2001) find that liquidity risk and taxes are more important determinants of corporate credit spreads than are default and recovery risk.

ability premium. We find that increases in the relative "tightness" (excess demand) in the auction of the nontradable contract versus the auction of the tradable spot bill are associated with lower nontradability premiums.

The article is organized as follows. Section II describes the Israeli Treasury market. In Section III, we develop the Nontradability Premium Hypothesis, which derives the equilibrium relation between the yields on the tradable and nontradable contracts, and which advances the determinants of the premium. The empirical evidence for January 1992–June 1997 is presented in Section IV. We also investigate the possible effects of differential tax treatment of realized (spot) and unrealized (forward) gains and losses at the end of the year.

In Section V, we extend our investigation to July 1997–December 2002, a period in which the Israeli Treasury market went through important structural changes. Major developments included active short selling of Treasury bills, trading in over-the-counter interest rate forwards, and changing the secondary market's trading mechanism from a trading once-a-day call auction to continuous trading. In contrast to the earlier data, the July 1997–December 2002 data may be subject to the shortcomings, which we discussed above, of earlier studies.

Finally, the evidence regarding the relation between yield and size (amount outstanding) for U.S. Treasury securities is unclear. On the one hand, a larger supply is typically associated with increased liquidity, which should result in lower yields. On the other hand, if the demand curves were downward sloping, an increase in supply would result in lower prices and higher yields. Warga (1992), Kamara (1994), and Krishnamurthy (2002) find that securities with larger amounts outstanding are more liquid and have lower yields, but Simon (1991, 1994) and Fleming (2002) find that increases in a bill's supply leads to higher yields.[8] We find that in January 1992–June 1997, investors required a higher yield to hold a larger quantity of a particular bill, implying that demand curves for Israeli Treasury bills sloped downward. But the improvements in the trading environment in July 1997–December 2002 increased the substitutability of different Treasury bills. Consequently, demand curves for Israeli Treasury bills no longer sloped downward. We conclude in Section VI.

II. The Treasury Bill Markets in Israel

The Treasury bills markets have operated in Israel since 1984 when the Bank of Israel started selling Treasury bills, which are pure discount securities and are not indexed to the consumer price index. In 1991, the Bank of Israel started offering contracts for future delivery of Treasury bills. Initially, contracts for future delivery, 3–4 months ahead, of 6- and 12-month bills were

8. Crabbe and Turner (1995) find no relation between size and yields in the corporate bond market.

sold. After June 1997 the bank stopped issuing contracts for future delivery of 6-month bills and began issuing contracts for future delivery of 3-month Treasury bills instead. (This change corresponds with similar changes in the issuance of spot Treasury bills.)

The Treasury bill markets consist of primary and secondary markets. In the primary market, the Bank of Israel offers Treasury bills and contracts for future delivery of Treasury bills to the public, via weekly auctions. In the secondary market, Treasury bills trade on the Tel Aviv Stock Exchange (TASE). Contracts for future delivery of 6-month bills in the amounts of 10 million NIS (New Israeli Shekel) were sold at each auction in 1992–94, and NIS 20 million per auction in January 1995–June 1997. Contracts for future delivery of 3-month bills in the amounts of NIS 20 million were sold at each auction in July 1997–September 2002, and NIS 40 million per auction afterward. In U.S. dollars, these amounts correspond with 0.4–0.7 billion contracts per year. The total annual amounts of bills auctioned grew from about NIS 7–8 billion in 1992–94 to about NIS 34 billion in 1997–98 to about NIS 43–47 billion in 2000–2002 (about $3 billion in 1992–94 and $10 billion in 1997–2002).

The contracts for future delivery state that the Bank of Israel undertakes to sell, and the buyers undertake to pay the bank, a sum in NIS according to their bids in the auction, against receipt of Treasury bills at some known future date. The contracts are not tradable and cannot be sold short. Thus, investors cannot close their positions in the contracts before the delivery date. Bidders who are successful in the auction are obliged to implement the transaction and also have to deposit a margin, which is returned to them at its nominal value, without interest, when the contract is exercised.

The contracts for future delivery are similar to futures contracts in the United States in that they have a "clearing corporation" (the Bank of Israel), which eliminates the possibility of default on the contracts. Default by sellers is nonexistent because the Bank of Israel is the only seller. The possibility of default by contracts' buyers is also negligible. Virtually all transactions in the contracts are between the Bank of Israel and the major banks and brokerage firms in Israel. The Bank of Israel employs safeguards against default by buyers. First, buyers deposit margins on their forward positions. Second, the open positions studied here are part of the entire set of open positions between the central bank and the banks and brokerage firms. The Bank of Israel has additional (side) contracts that guarantee all the open positions, including the ones studied here. The only possible ways that a bank or a brokerage firm can default on the contracts is that it will default on its entire set of open positions with the central bank and, in addition, that its margins are inadequate. This is very unlikely to occur. Since the beginning of trading in the contracts in 1991 and until today (August 2004), there have been no defaults on the contracts.[9]

9. The banks trade for their own account as well as acting as brokers. It is possible that a

The contracts are different from futures contracts and similar to forward contracts in the United States, in that they are not resettled (marked-to-market) daily. These characteristics are important. They imply that, unlike studies of futures and (synthetic) forward interest rate contracts in the United States (e.g., Kamara 1988; Grinblatt and Jegadeesh 1996), the nontradable and tradable (synthetic) contracts compared in our study have identical underlying cash flows over the time to delivery and are both free of credit risk. (The Bank of Israel is also the guarantor of the securities constituting the tradable synthetic contracts.)

The contracts for future delivery also differ from both futures and some forward contracts in the United States, in that they are nontradable contracts and also cannot be sold short. However, like the nontradable contract for future delivery, many forward contracts in the United States and around the world are bilateral agreements among investors, which are very costly to retrade before their expiration and usually cannot be sold short.

A. The Primary Market

In 1992–2002, the Bank of Israel sold Treasury bills and contracts for future delivery of Treasury bills once a week (on Tuesdays) via auctions open to the public. The auctions are sealed, multibid, discriminatory auctions. The bid-to-cover ratio in auctions is defined as the total amount of bids divided by the amount of bids accepted. The average bid-to-cover ratio for Treasury bills in our sample period is about six.[10] Initially, commercial banks dominated the trade in Treasury bills, holding about 60% of those sold in the TASE. Their market share declined to about 35% in recent years. Some 20 (of 28) members of the TASE participate in the auctions of contracts for future delivery on a regular basis.

Auctions for immediate and future delivery of Treasury bills are held in the same way and at the same time. At the beginning of each month, the Bank of Israel announces the dates and quantities of the auctions, and all auctions take place weekly at the same time, at 12:30 p.m., on Tuesdays. Members of TASE transfer instructions via the Automatic Banking Services communications system. The auctions are discriminatory auctions where bidders submit a competitive bid that consists of a yield to maturity-quantity pair. In a discriminatory auction every successful bidder gets the yield and quantity she bids. Bids at the closing yield are met in full or in part, in accordance with the quantity demanded at that yield. Results of the auction are transmitted to the participants about half an hour after it is held. Participants

client of the banks or brokerage firms may default on his or her position. This is a part of the safeguards used by the banks and brokerage firms vis-à-vis their clients. It does not play any role in the banks' and firms' relations with the Bank of Israel or in the forward market's safeguards.

10. For comparison, the average bid-to-cover ratio for government securities is about 2.5 in the United States (Jegadeesh 1993; Sundaresan 1994) and Sweden (Nyborg, Rydqvist and Sundaresan 2002) and 4 in Japan (Hamao and Jegadeesh 1998).

receive the following information: closing yield, average yield, and the quantity sold; at the same time they are notified of what quantity, if any, they were awarded, and at what yield. The demand in the auctions for the nontradable contract has always exceeded the total amount auctioned.[11] Unlike the U.S. Treasury market, there is no forward (when issued) market on the auctioned securities. Consequently, the only way to get the nontradable contract for future delivery is via the auction.

It is important to note that the total amounts of bills and contracts available to competitive bidders are known before the auctions. Indeed, all the bids in the auctions are competitive. In contrast, in U.S. Treasury auctions, while the total amount offered at the auction is known, the amount available to competitive bidders is uncertain. The amount available to competitive bidders in the United States is the residual left after the amount given to noncompetitive bidders, including the Federal Reserve and foreign central banks.

B. The Secondary Market in January 1992–June 1997

In the secondary market, Treasury bills trade on TASE. The bills have up to 12 months to maturity. In 1992–94, the annual turnover in Treasury bills was NIS 7–8 billion (about $3 billion). Since then, trading volume has grown almost every year. The turnover reached about NIS 34 billion ($9 billion) in 1997 and almost NIS 47 billion ($10 billion) in 2002. Treasury bills are more liquid assets than Treasury bonds and most other financial assets in Israel.

In this section we describe the secondary Treasury bill market during January 1992–June 1997. Subsequent changes in the market are discussed in Section V. In 1992–97, Treasury bills traded on TASE once a day in a call auction method, which works as follows.[12] Investors submit market and limit orders before the opening round. An investor who submits an order for a particular bill does not know its clearing price or the clearing prices of related bills. After the opening round investors have two short time intervals (rounds) in which they observe the excess demands and can submit additional "offsetting orders." That is, when the excess demand is positive they can submit sell orders only, and when the excess demand is negative they can submit buy orders only. Afterward, the auctioneer calculates the market-clearing prices for all Treasury bills, and all transactions in each bill are implemented at its market-clearing price. The clearing price of a particular bill is identical for all buyers and sellers. Once clearing prices are decided, investors cannot adjust their positions until the following trading day. Until 1995, human auctioneers conducted the auctions, and trading in Treasury bills generally took place between 1:00 p.m. and 2:00 p.m. Israeli time. After 1995, the call auction

11. While the bid-to-cover ratio always exceeded one in the U.S. and Japanese government auctions studied by Jegadeesh (1993) and Hamao and Jegadeesh (1998), the ratio was less than one in 7% of the Swedish Treasury auctions studied by Nyborg et al. (2002).

12. See Amihud, Mendelson, and Lauterbach (1997) for a detailed description of the call auction trading on TASE.

became computerized, similar in structure to the previous multilateral one, and trading in Treasury bill took place at 3:30 p.m. every trading day.

It is important to note that there was practically no short selling of Treasury bills during January 1992–June 1997. Until December 1995 it was illegal to short sell Treasury bills because TASE regulations prohibited it.[13] Though the short sale of bills was no longer illegal after 1995, it took awhile for TASE to change the bylaws and remove barriers that made short selling very costly. Consequently, there were practically no short sales of Treasury bills until almost 1998 (none in 1996 and a total amount of only about $2 million of Treasury securities [bills plus bonds] in 1997). In addition, investors cannot short sell the nontradable forward contracts.[14]

Kamara (1997) finds that relative spot U.S. Treasury bill yields also contain a premium for the risk that short sellers will default. In contrast, differences in our yields in January 1992–June 1997 should not reflect any credit risk because there were practically no short positions in our spot and forward bills; long positions in all spot and forward bills are guaranteed by the same institution, the Bank of Israel; default by buyers of forward contracts is extremely unlikely.

Finally, it is also important to note that, according to the Bank of Israel, the marginal ("main") traders in the secondary spot market are usually the same agents who are the marginal (main) bidders in the auctions. Consequently, there should usually be no differences regarding any private information revealed to other traders by the yields in the primary and secondary markets.

III. The Nontradability Premium Hypothesis

In this section we derive the equilibrium pricing relation between the tradable and nontradable securities and develop testable implications, based on nontradability, liquidity, and auction theories, regarding the determinants of time variation in the equilibrium pricing relation.

A. Equilibrium Relative Yields on Tradable and Nontradable Securities

To derive the equilibrium pricing relation between the tradable and nontradable securities we compare two equivalent riskless investment strategies. The first strategy consists of purchasing *T*-month spot Treasury bills. The second consists of buying synthetic *T*-month bills: a portfolio of *S*-month spot Treasury

13. Almost all the transactions in 1992–97 were by the major banks and brokerage firms in Israel. The securities we study constitute a very small fraction of their capital markets activities. The possible arbitrage profits are too small to induce them to violate TASE rules and put their entire TASE operations at risk. There were very few transactions by foreign investors, and foreign investors were also subject to the short sale prohibition.

14. In 1992–97 there were also no (over-the-counter) forward contracts or agreements, and there were no repo contracts. To the extent that there were other strategies, which are equivalent to short selling Treasuries, their cost over the Treasury yields that we use was large enough to preclude almost all profitable arbitrages between the securities that we study.

TABLE 1 **Costs, in Dollars, of Alternative Ways of Acquiring One 9-Month Treasury Bill**

Transactions on Current Date	Cost in U.S. Dollars: Today	After 3 Months	After 9 Months
Direct strategy:			
Buy one 9-month bill at a cost of $\$P_9$	P_9	0	−1
Synthetic strategy:			
Buy F_6 3-month bills at a cost of $\$P_3$ per bill	$F_6 \times P_3$	$-F_6$	
Buy one contract for future delivery, 3 months later, of one 6-month bill for a cost of $\$F_6$	0	F_6	−1
Total cost of synthetic strategy	$F_6 \times P_3$	0	−1

NOTE.—All the securities have a face value of $1. For simplicity, each cost already includes all the various trading costs and fees, including interest lost on margins.

bills ($S < T$) and nontradable contracts for future delivery, S months later, of (T–S)-month Treasury bills. For simplicity, let us use the securities that we study in 1992–97. The first strategy thus consists of buying 9-month bills, and the second strategy consists of buying the 3-month bills and the nontradable contracts for future delivery, 3 months later, of 6-month bills. The synthetic bill has identical characteristics to the actual bill, aside from the tradability aspect. Suppose, for simplicity, that all the securities have a face value of $1 and that each cost below already includes the price plus all the various trading costs, including any interest lost on margins.

Define:

$\$P_9$ The current cost of buying one 9-month spot Treasury bill.
$\$P_3$ The current cost of buying one 3-month spot Treasury bill.
$\$F_6$ The cost of buying, today, one contract for future delivery, 3 months later, of one 6-month Treasury bill. This cost is paid on the delivery day. For simplicity, the cash flow today is zero, and the interest lost on the margins is incorporated into $\$F_6$.

Table 1 describes the cash flows on the two riskless investment strategies over the 9 months. A very important feature of the equivalent strategies is that they do not involve any short selling. This is important because investors were unable to short sell the bills and contracts in our 1992–97 sample. In addition, in this part we assume that investors are tax neutral between the two strategies. During our sample period there was no personal tax on any income from Treasury securities. Firms were taxed on all sources of income using a flat corporate tax rate. We thus assume in this part that the tax treatment of the two strategies is identical.[15]

Table 1 shows that the current cost of buying the 9-month bill is $\$P_9$ and

15. This statement is true only when forward positions start and end in the same year. Corporations pay taxes once a year, at the end of the calendar year. Before 1997, realized gains and losses on spot bills were taxed, whereas unrealized gains and losses on forwards were not. This can affect the nontradability premium whenever forwards start and end in different years. We investigate this issue in Sec. IV.C. We thank the referee for this idea.

that the current cost of buying the synthetic 9-month bill is $\$(F_6 \times P_3)$, per \$1 face value. Ignoring the differences in tradability, we would expect the two costs to be equal.

ASSUMPTION 1. Investors are willing to pay for the option to retrade an asset.

Assumption 1 implies the following hypothesis.

> THE NONTRADABILITY PREMIUM HYPOTHESIS. Because the contract for future delivery is nontradable, investors are willing to pay less for the synthetic 9-month bill than they are willing to pay for the actual 9-month bill. That is, in equilibrium,
>
> $$(F_6 \times P_3) < P_9. \tag{1}$$

Because we are focusing on the nontradable contract for future delivery, let us rewrite the hypothesis as $F_6 < (P_9/P_3)$.

The yield to maturity on a T-month Treasury bill with a cost of P_T and a \$1 face value is:

$$1 + r_T = \left(\frac{1}{P_T}\right)^{12/T}. \tag{2}$$

Converting into yields to maturity, we can express the hypothesis as

$$(1 + f_6)^{6/12} > \frac{(1 + r_9)^{9/12}}{(1 + r_3)^{3/12}}, \tag{3}$$

where r_3, r_9, and f_6 denote the yields to maturity of the 3-month bill, 9-month bill, and the contract for future delivery of 6-month bills, respectively.

The Nontradability Premium Hypothesis postulates that

$$(1 + f_6)^{6/12} - \frac{(1 + r_9)^{9/12}}{(1 + r_3)^{3/12}}$$

is positive, in equilibrium, and is the extra yield that synthetic bill buyers require as compensation for forgoing the option to trade. We call this difference the “nontradability premium.”

A dual way to look at this is as follows. The term

$$\frac{(1 + r_9)^{9/12}}{(1 + r_3)^{3/12}}$$

is the implied 6-month forward rate for 3 months ahead. It is the yield implied in the spot yield curve on a synthetic forward contract, which is a portfolio of (1) a nontradable contract for future delivery, after 3 months, of a 6-month Treasury bill, and (2) an American option to sell an otherwise identical contract prior to its delivery date. The option has an uncertain exercise price, which equals the market price that will prevail on the day of the trade. For simplicity we will call the nontradable contract for future delivery "the nontradable contract" and the synthetic forward contract "the tradable contract."

B. The Determinants of the Nontradability Premium

Longstaff (1995) advances that the value of the option to trade is an increasing function of its price volatility or, in our case, interest rate volatility. The nontradability premium hypothesis thus postulates that the nontradability premium should be positively related to interest rate volatility.

The tradable securities in our sample are not perfectly liquid securities. Economic theory (see, e.g., the seminal paper of Amihud and Mendelson [1986]) suggests that investors are willing to pay higher prices for more liquid securities, ceteris paribus. Consequently, the extra cost that investors would be willing to pay to buy the tradable contract rather than the nontradable one should be higher, the more liquid the tradable contract. The nontradability premium hypothesis thus predicts that the nontradability premium should be positively related to the liquidity of the tradable contract.

We use the following variables to measure the liquidity of the 3- and 9-month (and, in Sec. V, 6-month) spot bills, the tradable constituents of the nontradability premium. The first two pairs of variables are the trading volumes and the amount outstanding of each of the two bills. The liquidity of a security is typically positively related to its trading volume and its size. The third pair of variables we use is each bill's turnover, which is measured as the ratio of the bill's trading volume over its amount outstanding. A higher turnover of a security is associated with a greater liquidity. In particular, a higher turnover is associated with a lower expected time required to trade at a "desirable" price (Garbade and Silber 1979; Lippman and McCall 1986; Kamara 1988, 1994).

The fourth pair of variables we use to measure the liquidity of the tradable spot bills is the product of the conditional interest rate volatility times each bill's turnover. Investigating U.S. Treasury securities, Kamara (1994) finds that turnover times interest rate volatility is a better measure of liquidity than turnover alone. The higher the volatility, the larger the marginal value of a reduction in the expected time required to trade at a desirable price.

An increase in the liquidity of a specific spot bill can reflect an increase in the liquidity of the spot bills market as a whole, an increase in the liquidity of that specific bill alone, or both.[16] An increase in the liquidity of both 9-month and 3-month bills because of an increase in the liquidity of the spot bill market as a whole should increase the opportunity cost of not being able to trade and, thus, increase the nontradability premium. But a bill-specific (or relative) increase in the liquidity of the 9-month and 3-month bills can affect their relative yields, which could have different effects on the implied forward

16. The coefficient of correlation between the trading volumes of the 3-month and 9-month bills is only 0.23.

yield and the nontradability premium. Recall that the nontradability premium is

$$(1 + f_6)^{6/12} - \frac{(1 + r_9)^{9/12}}{(1 + r_3)^{3/12}}.$$

A bill-specific increase in the liquidity of the 9-month bill should result in a decline in 9-month yields relative to 3-month yields. This will lower the implied forward yield and increase the nontradability premium. Hence, both market-wide and bill-specific increases in the liquidity of the 9-month bills should increase the nontradability premium. Consequently, we postulate that increases in the liquidity of 9-month (and, in Sec. V, 6-month) bills are associated with increases in the nontradability premium.

In contrast, a bill-specific increase in the liquidity of the 3-month bill should result in a decline in 3-month yields relative to 9-month yields. This will raise the implied forward yield and decrease the nontradability premium. Hence, the net effect of an increase in the liquidity of the 3-month bill on the nontradability premium is unclear.

The discussion so far ignores the fact that the nontradable contracts are sold in auctions. Auction theory (see the review in Bikhchandani and Huang [1993] for U.S. Treasury markets and the references therein) suggests that the larger the excess demand for the auctioned security, the higher its price and the lower its yield. The median value of the bid-to-cover ratio (the total amount of bids divided by the amount of bids accepted) for the nontradable contract on 6-month bills is almost 6.0, and its lowest value is 1.7.

Based on Boudoukh and Whitelaw (1993), we choose the ratio of the excess demand in the auction of the nontradable contract for future delivery over the excess demand in the 6-month spot auction as the variable that should capture the effects of the relative tightness on the nontradability premium. Boudoukh and Whitelaw (1993) predict that the larger this ratio of excess demands, the lower the nontradable yield relative to the tradable (spot-implied forward) yield. Hence, the nontradability premium should covary negatively with the ratio of the excess demand in the auction of the nontradable contract over the excess demand in the 6-month spot auction.

IV. The Empirical Evidence

The data for our study were obtained from the Bank of Israel. They are based on the results of the auctions of the contracts for future delivery of 6- and 3-month Treasury bills, with about 3 months to delivery, and daily transactions of spot Treasury bills that trade on the TASE. The sample period studied started in January 1992, about a year after the Bank of Israel started offering Treasury bills for future delivery. The first sample ended in June 1997, when the bank stopped issuing contracts for future delivery of 6-month Treasury bills. It covers the results of 285 weekly auctions. The second sample started on July 1997, when the bank began to issue contracts for future delivery of 3-month Treasury bills, and ended at the end of 2002. It covers the results of 215 weekly auctions. In this section we study the first sample. The second sample is studied in the next section.

We use the annualized yields to maturity on the contract for future delivery of 6-month Treasury bills, with 3 months to delivery, and the exactly matching 9-month and 3-month spot bills. The data were collected once a week on Tuesdays—the day of the auctions in the primary market. The bills and contracts settle with a one-day lag, and our yields take this into account. The yield on the contract for future delivery is the average yield in the auction. All yields are calculated net of all the costs of trading the securities. The costs include:

Distribution fees: As part of special arrangements, the Bank of Israel paid a distribution fee of 0.12% of the nominal value to TASE members who bought Treasury Bills at the bank's auctions. This commission was abolished in January 1997. Until then, members of the TASE almost always passed on most of it to the clients who bought at the auction through them. These fees were added to the yield of forward contracts in the period they applied.

Transaction costs: Participation in the auctions incurred no costs to the participants. Transactions on the TASE, however, required fees paid by the members of the TASE. They were 0.001% until August 1993, 0.002% until January 1994, and 0.005% since June 1995.

Margins: Participants in the auctions for forward contracts must deposit a margin. For contracts for future delivery of 6-month bills, the margin was 1% of their successful bid. For contracts for future delivery of 3-month bills, the margin is .5% of their successful bid. This deposit is returned to successful bidders at its face value. This cost of the lost interest is calculated by the margin rate multiplied by the market rate of interest for the relevant time to delivery.[17] This cost is added to the transaction costs.

A. The Nontradability Premium

The nontradability premium in January 1992–June 1997 was economically and statistically significant. The mean premium (net of all costs) over that period is 38 basis points (0.38%), with a *t*-statistic of 16.31 and a *p*-value

17. The 6-month forwards required a 1% margin over the 3 months to delivery. Suppose that the relevant interest for that period was 14%. Then the cost of lost interest for successful bidders is 0.0035 ($=0.14 \times 0.01 \times 3/12$). The cost of capital to the major banks is about .5% above the prime interest rate. We do not have the data by weekly observations, but a very conservative estimate is that this opportunity cost was higher than the interest rate we used by (at most) 2%. An additional 2% increases the cost of margins and reduces the nontradability premium that we report for 6-month forwards by 0.00005, and by half this amount for 3-month forwards.

less than 0.0001, and the standard deviation is 39 basis points.[18] Moreover, the premium was positive in 248 of the 285 observations (87%), which is significantly different than 50% at less than a 0.0001 level.

The nontradability premium is economically substantial. Although not shown, it is straightforward to translate the differences in yields into differences in the dollar income from holding the two contracts to maturity. Buyers of the traded contract could have increased their income by 3%, on average, by buying the nontradable contract instead. In 10% of the cases, they could have increased their income by more than 7%. Longstaff's (1995) valuation model of the option to trade advances that the nontradability premium is a positive function of price volatility and time to expiration. Thus, these premiums are considerable given that the nontrading period is only 3 months and Treasury bills are among the least volatile securities.

The mean value for the premium is of similar magnitude to the premium reported in Boudoukh and Whitelaw (1993) for Japanese government securities and to the premium reported in Amihud and Mendelson (1991) and in Kamara (1994) for illiquid short-term Treasury notes in the United States. It is smaller than the effect of nontradability on stocks and options reported in Silber (1991) and Brenner et al. (2001). Silber (1991) finds that restricting the tradability of privately placed stocks leads to an average discount of 35% relative to otherwise identical registered stock. Brenner et al. (2001) find that nontradable foreign-currency options trade at a discount of about 21% relative to otherwise identical options. Below, we show that the value of the nontradability premium is a positive function of price (interest rate) volatility. Interest rate volatility is typically much smaller than the volatility of stock and option returns. In addition, the nontradable contracts for future delivery in our study have 3 months to delivery, whereas the nontradability restrictions on the stocks in Silber (1991) are for 2 years, and the nontradable options in Brenner et al. (2001) have 3–6 months to expiration.

There are two potential problems with the nontradability premiums calculated here. First, the trading mechanisms of the auctions in the primary and secondary Treasury markets are different. Second, the yields on the traded contract (spot 3- and 9-month bills) and the nontradable contract are not synchronized within the day. It is possible, for example, that some of the observations with negative premiums (which constitute 13% of the sample) are due to the different trading mechanisms and nonsynchronous quotes.[19]

18. The yield we use for the contract for future delivery is the average yield in a discriminatory auction. It is usually lower than the market-clearing price in the auction, which is the highest accepted bid yield, sometimes called the "stop-out," or closing, yield. Consequently, our estimated nontradability premium understates the true premium. We do not have weekly data on stop-out yields. An examination of the annual averages of the closing yields and average yields on the forward auctions suggests that using average yields instead of closing yields causes us to underestimate the nontradability premium by 6–9 basis points.

19. They could also reflect the excess demand in the auction of the nontradable contract relative to the excess demand in the spot auction. As predicted by Boudoukh and Whitelaw (1993), the larger this ratio of excess demands, the lower the nontradable yield relative to the tradable yield. We will investigate this effect below.

The only way in which we can get some idea about the seriousness of these problems is by examining the difference between the yields on the auctioned and spot (i.e., primary and secondary) 6-month bills, which are also traded at the same times on the same day. This spread should capture both of these factors. The 6-month bills and the contract for future delivery are issued in the primary market using identical auction mechanisms that occur at the same time. Likewise, the spot 3-, 6-, and 9-month bills trade on the secondary market in call auctions with identical trading mechanisms that calculate the market-clearing price for all these bills at the same time.

The mean annualized difference between the auction yield and spot yield on 6-month bills is 0.0001 (one basis point), with a t-statistic of 0.75 (and a significance level of 0.45). The median is 0.00015. We cannot reject the hypothesis that the proportion of positive values is 0.50 (a z-statistic of 1.25 and a significance level of 0.21). This suggests that the effect of different auction mechanisms and nonsynchronous quotes on the magnitude of the mean nontradability premium is likely to be negligible. It also suggests that the bills are not underpriced in the primary market relative to the secondary market.[20]

We also investigated whether the uncertainty (or noise) due to nonsynchronous yields has a significant effect on the nontradability premium. We regressed the nontradability premium on (contemporaneous and lagged) values and the squared values of the difference between the auction and spot 6-month yields. We cannot reject the (separate or joint) null hypotheses that there is no effect at conventional levels. Finally, we also repeated all the tests above using the spread between the 6-month auction yield and the previous day's spot 6-month yield. Though the mean spread is slightly higher (3 basis points), all our conclusions are unchanged.[21]

B. The Determinants of the Nontradability Premium

In this section we examine the determinants of the time variation in the premium. Figure 1 plots the time series of the nontradability premium. The graph indicates considerable time variation in the premium. The plot has two observations with substantially negative nontradability premiums. In both cases the likely main reason for the substantially negative nontradability premium is that the "traded" yield was substantially higher than in previous weeks. We have a possible explanation for these observations (specially for the first one). Nevertheless, regardless of why these observations occurred,

20. Cammack (1991) and Spindt and Stolz (1992) find that U.S. Treasury bills were underpriced in the primary market relative to the secondary market. In the Israeli market, unlike the U.S. Treasury market, all bids are competitive, which means that the total amounts of bills and contracts available to competitive bidders are known before the auctions, and there is no forward (when issued) market on the auctioned securities.

21. Recall that we calculate the premium using the auction's average yield rather than the (higher) stop-out yield. The difference between the stop-out and average yields may depend on yield volatility during the day, which can also be proxied by the squared values of the difference between the auction and spot 6-month yields on that day. Hence, our tests also suggest that this bias is not likely to have a significant effect on time variation in the premium.

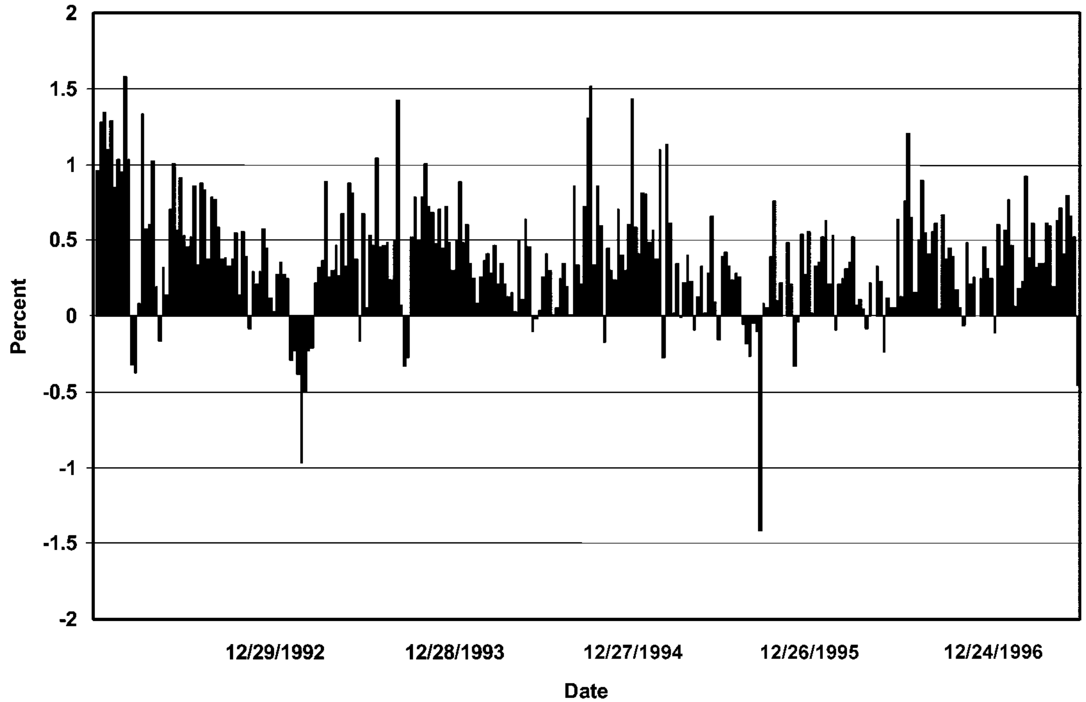

FIG. 1.—The nontradability premium, January 1992–June 1997

we have repeated all the regressions below, excluding these two observations. All our conclusions remain the same.

Boudoukh and Whitelaw (1993) advance that the nontradability premium depends negatively on the relative tightness of the two auctions. We use the ratio of the excess demand in the auction for the nontradable contract for future delivery over the excess demand in the auction for the 6-month bill to capture the relative tightness. The two observations with substantially negative nontradability premiums appear to reflect unusual relative tightness, which follows larger than usual amounts of spot bills auctioned by the Treasury in the preceding weeks. In particular, the first observation (on February 23, 1993) occurred immediately (1 week) after our proxy for relative tightness had its highest value in our sample. Moreover, this value of 1.8 is much higher than the second highest value of 1.1 (the only other observation that is greater than one) and the average value of 0.3.[22]

Table 2 reports the empirical results regarding the determinants of time variation in the nontradability premium. All the regressions also include the first three lags of the nontradability premium as additional regressors.[23] The regressions differ in that each regression uses different liquidity measures.

Consistent with Longstaff (1995), the nontradability premium is positively related to estimated interest rate volatility. The relation is statistically significant at less than 2%. The estimated interest rate volatility is the predictor from a Generalized Auto Regressive Heteroskedasticity model, GARCH(1,1), of lagged changes in 3-month Treasury bill yields. We find empirical support for the hypothesis that an increase in interest rate volatility increases the value of the option to trade and the opportunity cost of not being able to trade. As a result, the price discounts that buyers require to buy the nontradable contract instead of the traded contract increase.

Consistent with Boudoukh and Whitelaw (1993), we find that the nontradability premium (which is also the difference between the auction bid, nontradable "forward" rate and the spot-implied, tradable forward rate) covaries negatively with the ratio of the excess demand in the forward auction over the excess demand in the spot auction. We calculate the excess demand in each of the auctions as the difference between the total bids tendered to the amount auctioned. The coefficients on the relative excess demand variable are negative at the 1% significance level. The result is consistent with the

22. The data reveal substantial increases in the demand for contracts for future delivery together with substantial declines in the demand for the spot bill, relative to previous weeks, in the auctions on February 23, 1993, and February 16, 1993. This follows larger than usual amounts of 6-month bills auctioned in the preceding weeks. The second observation (on September 1995) is also associated with a substantial decline in the demand for the spot bill relative to previous weeks, following larger than usual amounts of spot 6-month bills auctioned in the preceding auctions.

23. For each of the regressions in table 2, we conducted a dynamic linear specification approach, which augments the regression with lags of the dependent and independent variables. We started with a model of four lags for each of the variables and tested downward to get a more specific model. The approach reveals the need to include the first three lags of the nontradability premium (only) to each of the regressions. We thank Eric Zivot for this suggestion.

TABLE 2 **The Determinants of the Nontradability Premium in Contracts for Future Delivery of 6-Month Treasury Bills: Weekly, January 1992–June 1997**

	Regression Coefficient (p-Value)		
Variable	Liquidity Measured by Volume	Liquidity Measured by Turnover	Liquidity Measured by Volatility × Turnover
Constant	2.0093	1.9155	1.8865
	(.0050)	(.0072)	(.0074)
VOLATILITY	.6216	.6230	.5828
	(.0125)	(.0128)	(.0181)
EXCESS DEMAND	−.2979	−.3123	−.3232
	(.0062)	(.0032)	(.0017)
OUTSTAND9M	−.1194	−.0964	−.0943
	(.0016)	(.0076)	(.0087)
VOLUME9M	.0278		
	(.0988)		
TURNOVER9M		5.9266	
		(.0853)	
VOLATILITY × TURNOVER9M			18.5475
			(.0281)
Nontradability premium ($t-1$)	.2579	.2588	.2576
	(.0001)	(.0001)	(.0001)
Nontradability premium ($t-2$)	.1804	.1758	.1746
	(.0067)	(.0090)	(.0090)
Nontradability premium ($t-3$)	.1231	.1207	.1208
	(.0247)	(.0271)	(.0250)
R^2	.2922	.2913	.2951
Adjusted R^2	.2714	.2705	.2745

NOTE.—The nontradability premium is equal to

$$\left[1+\left\langle(1+f_6)^{6/12}-\frac{(1+r_9)^{9/12}}{(1+r_3)^{3/12}}\right\rangle\right]^2-1,$$

where r_3, r_9, and f_6 are the annual yields to maturity of 3- and 9-month Treasury bills, and contracts for future delivery (after 3 months) of 6-month Treasury bills. The nontradability premium is annualized, in percent, and net of all costs. VOLATILITY is the lagged interest rate volatility estimated as a GARCH(1,1) process. EXCESS DEMAND is the excess demand in the auction of the contracts for future delivery divided by the excess demand in the auction of 6-month bills. OUTSTAND9M is the natural log of the current week's outstanding amounts of 9-month bills. VOLUME9M is the natural log of the previous week's trading volumes of 9-month bills. TURNOVER9M is the previous week's turnover (defined as trading volume over amount outstanding) of 9-month bills. There are 285 observations. Heteroskedasticity-consistent p-values are in parentheses.

predictions of auction theory that a larger excess demand is associated with a higher price and a lower yield.

Let us turn to the liquidity variables. The regressions in table 2 use only liquidity variables for the 9-month spot bill. Each regression was also repeated with (adding) liquidity variables for the 3-month spot bill, which are identical to the specific set of liquidity variables used for the 9-month bill in that regression. The regressions were also repeated with different sets of liquidity variables for the 3-month spot bill and without any liquidity variable for the 9-month bill. The liquidity variables for the 3-month bill were never significant, separately or jointly, at any acceptable significance level. Hence, we fail to find any evidence that the liquidity of the 3-month bill has any effect on the nontradability premium. Recall that theory says that the net effect of an increase in the liquidity of the 3-month bill on the nontradability premium is unclear. For brevity, and because the adjusted R^2 values were always higher when the regressions excluded liquidity variables for the 3-month bill, table 2 reports the regressions without liquidity variables for the 3-month spot bill. Our conclusions are unaffected when liquidity variables for the 3-month bill are included as well.

The opportunity cost of buying the nontradable contract rather than the tradable contract increases as the tradable contract becomes more liquid. Therefore, the nontradability premium should increase as the tradable contract becomes more liquid. The liquidity of a security is usually positively related to its trading volume and its size. The first regression uses (natural logs of) the trading volumes and amount outstanding of the 9-month spot bill. We expect that an increase in either variable would increase the nontradability premium.

For this study, the Bank of Israel has collected these data once a week on Thursday. The trading volume data are always the data reported for the Thursday preceding the auction. The data on the amount outstanding are for the Thursday following the auction. The reason is that although the data on the amount outstanding are collected 2 days after the auction, they were known to traders on the auction day. Moreover, last week's amount outstanding may include bills that no longer have 9 months to maturity. Nevertheless, we repeated the regression using the amount outstanding from the Thursday preceding the auction. Our results are not sensitive to that choice.

The first regression reveals that the nontradability premium is positively related to the trading volume of the 9-month spot bill, but only at about the 10% significance level. In contrast, the nontradability premium is negatively related to the amount outstanding of the 9-month spot bill, at less than a 1% significance level. At first glance it appears that the negative coefficient on the amount outstanding of the 9-month spot bill is inconsistent with the joint hypotheses that the nontradability premium is positively related to the liquidity of the 9-month spot bill and that the liquidity of the 9-month spot bill is positively related to its amount outstanding. However, later we will offer another (nonliquidity) explanation for this negative relation. Accordingly, the other regressions include the amount outstanding variable in addition to liquidity variables.

The second regression uses the turnover of the 9-month spot bill (the ratio of trading volume over amount outstanding, measured on the week proceeding the auction) as the liquidity proxy. The nontradability premium is positively related to the turnover of the 9-month spot bill, but only at about the 8.5% significance level.

The third regression uses the product of estimated volatility times the turnover as the liquidity proxy. Its coefficient is positive at less than a 3% significance level.

Notice that the three regressions have the same information set. The first regression includes volatility, amount outstanding, and trading volume as separate explanatory variables, and trading volume is significant only at about 10%. The second regression includes volatility, amount outstanding, and turnover (trading volume over amount outstanding) as separate explanatory variables, and turnover is significant only at about 8.5%. In contrast, the third regression includes volatility, amount outstanding, and volatility times turnover as separate explanatory variables, and volatility times turnover is significant at 2.81%. In addition, the third regression has the highest R^2 and adjusted R^2 values in table 2, and our conclusions regarding volatility and amount outstanding are unaffected. Thus, table 2 implies that turnover times volatility is a more appropriate way to measure the liquidity risk of the 9-month bill than either turnover or trading volume. This suggests that interest rate volatility and expected time to transact are not independent attributes of liquidity risk. Rather, liquidity risk is an increasing function of the interest rate volatility times the expected time to transact.

Notice that when liquidity is measured by volatility times turnover, the partial coefficient of estimated volatility remains significantly positive and its magnitude only falls from 0.62 to 0.58. This suggests that volatility significantly affects the nontradability premium beyond its effect on the liquidity risk of the 9-month bill, which is consistent with Longstaff (1995).

Finally, the coefficient of the amount outstanding remains significantly negative at less than a 1% significance level in the second and third regressions. The hypothesis that the liquidity of an asset is positively related to its size suggests that liquidity should increase with the amount outstanding. This implies that the nontradability premium should increase with the amount outstanding of the 9-month bill. But the coefficients of the amount outstanding of 9-month bills are significantly negative in each of the regressions. It is possible that this is because the liquidity of an asset is also positively related to its turnover, which is measured as the trading volume over the amount outstanding. The trading volume and the amount outstanding enter the first regression as separate variables, so that the negative (partial) coefficient of the amount outstanding measures the effect of an increase in the amount outstanding when the trading volume is held constant. If, for the amount outstanding, the turnover effect dominates the size effect, its partial coefficient would be negative. Table 2 suggests, however, that this is not the reason why the coefficients of the amounts outstanding are significantly negative. The second and third regressions include the amount outstanding in the auction's week in addition to either the turnover or the product of turnover times volatility. The partial coefficient of the amount outstanding of 9-month bills remains significantly negative (at less than 1%), with an estimated value of −9 basis points, even after accounting to the effects of the turnover of 9-month bills.

There is, however, another possible reason why the coefficient of the amount outstanding is negative. Simon (1991, 1994) and Fleming (2002) find that investors require higher yields to hold additional quantities of particular bills and notes. This suggests that demand curves for particular Treasury bills in the United States are downward sloping. The hypothesis of downward sloping demand curves implies that the spot 9-month bill yield, and thus the implied forward rate, should increase with the amount outstanding of the 9-month bill; the nontradability premium should decrease with the amount outstanding of the 9-month bill.

There is a debate in finance on whether demand functions for financial assets have infinite price elasticity.[24] The problem is that price declines as a function of quantity offered could be due to shifts in asset demand functions owing to adverse information revealed by the sale, because the demand curve is downward sloping, or both. Hence, evidence of price declines as a function of quantity offered is not necessarily a rejection of the infinite demand price elasticity hypothesis. Because the tests above use a spread between the yields on two assets, which are identical in all characteristics aside from tradability, the tests are free of informational problems. Moreover, since liquidity is positively associated with size, even if one may argue that the amount outstanding captures some aspect of liquidity for which we failed to fully control, its partial coefficient should be positive. Hence, if the 9-month bills' demand function is horizontal, the effect of the amount outstanding on the nontradability premium could not be negative. Consequently, our evidence that the partial coefficient of the amount outstanding is significantly negative is evidence that the 9-month bills' demand curve is downward sloping. Note, however, that our rejection of the hypothesis that demand price elasticity is infinite could result from the fact that investors were not able to short sell Treasury bills in this period.

C. The End-of-Year Effect

The banks and brokerage firms, which are the major players in the markets, pay taxes once a year, at the end of the calendar year. Until 1997, realized gains and losses on the spot bills were taxed, whereas unrealized gains and losses on the forwards were not taxed. This could have affected the premium whenever forward positions started and ended in different calendar years.

We examined this issue in two ways. First, we examined the effect on the size of the premium. It is important to understand that, in January 1992–June 1997, (i) the tax rates on gains and losses were the same and (ii) the traders did not have a tax-timing option because they did not have an option to close their forward contracts before their expiration in order to minimize their total taxes. Hence, the effect of taxes on the nontradability premium could go either way. That is, the effect on the nontradability premium of paying or "receiving"

24. Hess and Frost (1982) examine increases in supplies of seasoned equity and do not reject the infinite price elasticity hypothesis. Kandel, Sarig, and Wohl (1999) find that demand schedules for Israeli initial public offerings are flat around the auction-clearing price. For other studies on whether equity demand functions are downward sloping, see Cha and Lee (2001) and the references therein.

taxes on realized spot gains and losses versus no taxes on unrealized forward gains and losses was sometimes positive and sometimes negative. Consequently, we do not expect any systematic effect on the size of the premium. It should also be noted that because short sales were nonexistent and forward contracts are nontradable, it is unlikely that tax advantages for one security over the other were completely arbitraged away.

We divided the January 1992–June 1997 sample into two subsamples. The first subsample includes all the cases in which the forwards and spot positions start and end in the same calendar year. The second subsample includes all the cases in which the forwards and spot positions start and end in different calendar years. The mean premium in the second subsample is (insignificantly) lower than the mean premium in the first subsample by about one basis point (annualized).

Second, we examined the effect on the determinants of the premium. We used a dummy variable for observations in which the forwards and spot positions start and end in different calendar years. We repeated the regressions above by adding the dummy variable and the products of the dummy with each of the explanatory variables in the regression. All our conclusions above remain the same. In addition, all but one of the products of the dummy with the explanatory variables are insignificantly different from zero. The effect of the relative tightness (the ratio of the excess demand in the auction of the nontradable contract for future delivery over the excess demand in the 6-month spot auction) is, however, stronger (more negative) when the forwards and spot positions start and end in different years than otherwise. The coefficient of the product of relative tightness with the dummy is significantly negative at the 5% level. Further investigation reveals that the excess demand in the 6-month spot auction is higher by about 10% (significant at about the 6% level) when the positions start and end in different calendar years than otherwise. In contrast, the excess demand in the auction of the nontradable contract for future delivery is (insignificantly) lower by 2.5%. It appears that traders take the differential taxes into effect when they choose which security to buy. Also, controlling for the effect of differential tax treatment on excess demand, the coefficient on the dummy (alone) is positive at 5%.

The evidence supports the hypothesis that the differential tax treatment of realized versus unrealized gains and losses affected the relative excess demands for the securities. This has resulted in a stronger (more negative) relation between the relative tightness and the nontradability premium at the end of the year.

V. The Post-June-1997 Experience

In July 1997 the Bank of Israel stopped issuing nontradable contracts for future delivery of 6-month bills and began issuing nontradable contracts for future delivery (3 months ahead) of 3-month Treasury bills instead.

At about that time the Israeli Treasury markets also started going through a series of important developments that have changed the trading environment considerably. These changes have ended the almost-perfect laboratory conditions that existed in January 1992–June 1997.

The first development was the emergence of active short selling of bills in 1998. The second development was the trading in over-the-counter interest rate forward contracts. The TASE began trading interest rate forwards in 1999, but trading volumes have been very small. The major banks started trading over-the-counter interest rate forwards in 2000, and trading has been active. These developments offer new and, possibly, less costly ways to arbitrage and replicate the tradable and nontradable assets.

The third development was an important change in the trading mechanism of Treasury bills on TASE. Until December 1998, Treasury bills traded on TASE once a day, in a call auction. On December 1998, Treasury bills began trading continuously throughout the day. This implies that traders can now immediately take advantage of any information revealed by the auctions (in 1992–97 they had to wait until the following day). They can also spread their trades within the day instead of having to trade their entire desired amount once a day.

The two alternative strategies used to derive the nontradability premium embedded in the prices of the nontradable contract for future delivery, 3 months ahead, of 3-month bills are (i) directly buying the 6-month bill and (ii) buying the 3-month bill and the nontradable contract. The (nonannualized) nontradability premium is

$$(1 + f_3)^{3/12} - \frac{(1 + r_6)^{6/12}}{(1 + r_3)^{3/12}},$$

where r_3, r_6 and f_3 denote the yields to maturity of the 3-month bill, 6-month bill, and the contract for future delivery, 3 months ahead, of 3-month bills, respectively.

The July 1997–December 2002 data could be subject to the shortcomings of earlier studies. For example, Kamara (1988, 1997) reports that relative (6-month vs. 3-month) spot Treasury bill yields in the United States also contain a premium for the risk that short sellers will default, and that this premium increases with interest rate volatility. To the extent that these findings also hold for our July 1997–December 2002 yields, they would increase the term

$$\frac{(1 + r_6)^{6/12}}{(1 + r_3)^{3/12}}$$

and, thus, reduce the premium above. They would also reduce the net effect of interest rate volatility on the premium.

In this section we examine the determinants of the nontradability premium above during July 1997–December 2002.[25] The average (annualized) nontradability premium during July 1997–December 2002 was 31 basis points, with a t-statistic of 11.54 and a p-value lower than .0001; the standard deviation is 22 basis points.[26] The premium was positive in 82% of the cases, which is significantly different than 50% at less than a 0.0001 level.

To study the determinants of the nontradability premium in July 1997–December 2002, we repeated the regressions discussed in Section IV, using the underlying 6-month bill instead of the 9-month bill. The results are in table 3. We continue to find support for Longstaff (1995) and Boudoukh and Whitelaw (1993). Consistent with Longstaff (1995), the nontradability premium is significantly positively related to interest rate volatility. The volatility's coefficients are around 0.30 and are statistically significant with .05–.06 p-values in all the regressions. Consistent with Boudoukh and Whitelaw (1993), the nontradability premium is significantly negatively related to the ratio of the excess demand in the forward auction over the excess demand in the spot auction. The ratio's coefficients are around -0.40 and are statistically significant .02–.03 p-values in all the regressions.

In contrast, the effects of the amount outstanding of 6-month bills and the liquidity of 6-month bills are not statistically significant in the new sample. None of the liquidity variables used in the regressions (for 6-month, instead of 9-month, bills) is statistically significant at conventional levels. This reflects three developments. First, equilibrium prices are now also determined by arbitrageurs who today buy and short sell the appropriate bills and hold them until the delivery date, and by arbitrageurs who trade over-the-counter forwards. As a result, they are less concerned than the traders in the 1992–97 sample about the future liquidity of the underlying bills. Second, improvements in the trading environment have reduced the effects of the imperfect liquidity of spot bills. In particular, since December 1998 traders can trade continuously (and spread trades) throughout the day rather than once a day in a call action. Traders can also trade immediately after the auctions results are known and do not have to wait until the next trading day, as they had to do in 1992–97. Third, the underlying bill is much more liquid. The trading volumes of all bills are much larger in 1997–2002 than before, and, in addition, the 6-month bill is more liquid than the 9-month bill.[27] As a result, time variations in the

25. Our sample does not include the second half of 2000. In 2000 the Israeli government recommended important changes in taxes of spot and forward Treasury bills. Because of the complex implications of the new taxes and uncertainty regarding implementation of the changes, the Bank of Israel did not issue any 3-month forwards from June 2000 until the beginning of 2001, after which the recommendations died without being implemented. Tax changes were eventually implemented in 2003.

26. During December 1998–December 2002, we only have end-of-day (i.e., last transaction of the day) spot yields. Hence, our premiums in that period are calculated using end-of-day spot yields.

27. For example, the average trading volume of 9-month bills in July 1997–December 2002 is 3.7 times its value in January 1992–June 1997; the average ratio of the trading volume of 6-month bills over the trading volume of 9-month bills in July 1997–December 2002 is 2.6.

TABLE 3 **The Determinants of the Nontradability Premium in Contracts for Future Delivery of 3-Month Treasury Bills: Weekly, July 1997–December 2002**

	Regression Coefficient (p-Value)		
Variable	Liquidity Measured by Volume	Liquidity Measured by Turnover	Liquidity Measured by Volatility × Turnover
Constant	1.3628	1.4947	1.2222
	(.3844)	(.3549)	(.4401)
VOLATILITY	.2984	.2941	.3143
	(.0578)	(.0643)	(.0494)
EXCESS DEMAND	−.4189	−.4092	−.4255
	(.0166)	(.0233)	(.0140)
OUTSTAND6M	−.0556	−.0672	−.0541
	(.4504)	(.3709)	(.4614)
VOLUME6M	−.0075		
	(.6693)		
TURNOVER6M		.3636	
		(.9251)	
VOLATILITY × TURNOVER6M			−6.4948
			(.4560)
Nontradability premium ($t-1$)	.2361	.2386	.2334
	(.0046)	(.0043)	(.0053)
Nontradability premium ($t-2$)	.0541	.0510	.0587
	(.5107)	(.5359)	(.4837)
Nontradability premium ($t-3$)	.2314	.2326	.2297
	(.0213)	(.0212)	(.0230)
R^2	.2555	.2536	.2550
Adjusted R^2	.2270	.2249	.2264

NOTE.—The nontradability premium is equal to

$$\left[1+\left\langle(1+f_3)^{3/12}-\frac{(1+r_6)^{6/12}}{(1+r_3)^{3/12}}\right\rangle\right]^4-1,$$

where r_3, r_6, and f_3 are the annual yields to maturity of the 3- and 6-month Treasury bills, and contracts for future delivery (after 3 months) of 3-month Treasury bills. The nontradability premium is annualized, in percent, and net of all costs. VOLATILITY is the lagged interest rate volatility estimated as a GARCH(1,1) process. EXCESS DEMAND is the excess demand in the auction of the contracts for future delivery divided by the excess demand in the auction of 6-month bills. OUTSTAND6M is the natural log of the current week's outstanding amounts of 6-month bills. VOLUME6M is the natural log of the previous week's trading volumes of 6-month bills. TURNOVER6M is the previous week's turnover (defined as trading volume over amount outstanding) of 6-month bills. There are 215 observations. Heteroskedasticity-consistent p-values are in parentheses.

(imperfect) liquidity of the underlying bill no longer have a significant effect on the premium.[28]

The coefficients of the amount outstanding of 6-month bills, though still negative in all the regressions, are about one-half of their magnitude in table

28. Note, however, that the effect of volatility may now be more difficult to discern than in 1992–97. Though higher volatility may be associated with a higher positive liquidity effect (in addition to a higher value of the nontradability option), it may also be associated with a higher negative short sales' default effect.

2 and are not statistically significant at conventional levels. This is consistent with the explanation that our rejection of the infinite demand elasticity hypothesis in 1992–97 is at least partially due to the fact that investors were unable to short sell Treasury bills. It also suggests that the improvements in the functioning of the markets have increased the substitutability of different Treasury bills.[29]

Finally, the differential tax treatment of realized versus unrealized gains and losses also ended in 1997. During 1997–2002, unrealized gains and losses at the end of the year were marked-to-market and taxed in an identical manner to realized gains and losses. Not surprisingly, when we repeated the tests in Section IV.C, for July 1997–December 2002, we could not reject the hypotheses (separately and jointly) that whether or not the spot and forward positions start and end in the same calendar year does not have any effect. This strengthens the case that the results in Section IV.C do indeed represent the effects of differential tax treatment.

VI. Conclusion

The methodology of finance is the use of traded securities to price twin financial and real assets. Whatever the valuation methodology, prices of traded securities are almost always used to value twin nontradable assets and projects, with the effects of nontradability ignored. Our results suggest that the equilibrium values of nontradable and otherwise identical tradable assets can be quite different. We also explore the factors that affect these differences.

We investigate the values of the tradability and liquidity of securities using a unique sample of nontradable contracts for future delivery of Treasury bills issued by the Bank of Israel, which have identical tradable securities that trade on the secondary market. The structure of the Israeli Treasury bill markets supports the model of Boudoukh and Whitelaw (1993), in which segmenting markets along the dimension of liquidity is the optimal way of discriminating between different types of investors and extracting consumer surplus.

Our study makes a valuable contribution to the study of nontradability and liquidity because our data from January 1992–June 1997 allow us to overcome important shortcomings of earlier studies on fixed income securities and derivatives. In addition to liquidity differences, relative (spot, forward, and futures) Treasury yields in the United States often also reflect premiums for the risk that short sellers will default; differential taxes; and cash flow differences

29. It could also reflect the fact that the amounts outstanding of 6-month bills in July 1997–December 2002 are typically higher than in January 1992–June 1997; more important, their variability is much smaller in July 1997–December 2002 than in January 1992–June 1997. The average amount outstanding of the 6-month bill in 1997–2002 is about 3.4 times the average amount outstanding of the 9-month bill in January 1992–June 1997. (The amounts outstanding of 6- and 9-month bills are not significantly different.) In contrast, the variance of the amount outstanding of 6-month bills in 1997–2002 is about one-third of the variance of the amount outstanding of 9-month bills in January 1992–June 1997.

stemming from the daily marking-to-market of futures, but not forward, contracts. It is not usually possible to completely disentangle these effects on U.S. Treasury yields because, as economic theory suggests, credit risk, liquidity risk, tax options, and the effects of daily margin calls in interest rate futures markets are all positive functions of interest rate volatility. Moreover, the profitability of tax arbitrages and effects of default risk are also related to the assets' liquidity. These confounding effects were not present in the Israeli market in January 1992–June 1997. The Israeli Treasury bill market in that period, therefore, offers unique, almost perfect, laboratory conditions to study the factors affecting the value of the tradability and liquidity of an asset.

We define the nontradability premium as the difference between the yield on the nontradable contract and the yield on the otherwise identical tradable contract. Buyers of the nontradable contract require an additional return to compensate them for the opportunity cost of not having an option to trade. The average nontradability premium in January 1992–June 1997 is 38 basis points.

Longstaff's (1995) model of the option to trade advances that the nontradability premium is a positive function of price volatility and time to expiration. Consistent with Longstaff (1995), we find that the premium, which is also the market value of the option to trade, is a positive function of interest rate volatility. The nontradability premium is thus substantial given that the nontrading period is only 3 months and Treasury bills are among the least volatile securities.

While the nontradable contract is perfectly illiquid, the tradable contract is not perfectly liquid. We find that the premium in January 1992–June 1997 was positively related to the product of the conditional interest rate volatility times the underlying bill's turnover. We also find that this product is a better liquidity proxy than other commonly used measures. A higher turnover of a security is associated with a lower expected time required to trade at a desirable price. The higher the volatility, the larger the marginal value of a reduction in the expected time required to trade at a desirable price.

Auction theory postulates that there is a negative relation between the auction's yield and the excess demand for the security auctioned. Our results support the predictions of auction theory and, in particular, Boudoukh and Whitelaw (1993). We find that increases in the relative tightness (excess demand) in the auction of the nontradable contract versus the auction of the tradable spot bill are associated with lower nontradability premiums.

In 1997 the Israeli Treasury market began implementing important changes. The major developments include short selling of bills, trading over-the-counter forward contracts, and changing the trading mechanism of the secondary market from a once-a-day call auction to continuous trading. An examination of the 1997–2002 period lends further support for Longstaff (1995) and Boudoukh and Whitelaw (1993). The evidence also suggests that improvements in the trading environment and substantial increases in the trading volumes of Treasury bills have reduced the effects of time variations in illiquidity on the premium and have increased the substitutability of different Treasury bills.

References

Amihud, Yakov, and Haim Mendelson. 1986. Asset pricing and the bid-ask spread. *Journal of Financial Economics* 17:223–49.

———. 1991. Liquidity, maturity and the yields on U.S. government securities. *Journal of Finance* 46:1411–26.

Amihud, Yakov, Haim Mendelson, and Beni Lauterbach. 1997. Market microstructure and securities values: Evidence from the Tel Aviv Stock Exchange. *Journal of Financial Economics* 45:365–90.

Bank for International Settlements. 2003. BIS quarterly review, statistical annex, Bank for International Settlements, Basel, Switzerland, September, http://www.bis.org/pub/qtrpdf/r_qa0309.pdf#page=99 (last accessed October 19, 2004).

Bikhchandani, Sushil, and Chi-Fu Huang. 1993. The economics of Treasury securities markets. *Journal of Economic Perspectives* 7:117–34.

Black, Fischer, and Myron Scholes. 1973. The pricing of options and corporate liabilities. *Journal of Political Economy* 81:637–59.

Boudoukh, Jacob, and Robert F. Whitelaw. 1991. The benchmark effect in the Japanese government bond market. *Journal of Fixed Income* 1:52–59.

———. 1993. Liquidity as a choice variable: A lesson from the Japanese government bond market. *Review of Financial Studies* 6:265–92.

Brenner, Menachem, Rafael Eldor, and Shmuel Hauser. 2001. The price of option's illiquidity. *Journal of Finance* 56:789–805.

Buffett, Warren E. 2003. Chairman's letter. In *Berkshire Hathaway Inc.: 2002 annual report*, 3–23. Omaha, NE: Berkshire Hathaway.

Cammack, Elizabeth B. 1991. Evidence on bidding strategies and the information in Treasury bill auction. *Journal of Political Economy* 99:100–130.

Cha, Heung-Joo, and Bong-Soo Lee. 2001. The market demand curve for common stock: Evidence from equity mutual fund flows. *Journal of Financial and Quantitative Analysis* 36:195–221.

Crabbe, Leland E., and Christopher M. Turner. 1995. Does the liquidity of a debt issue increase with its size? Evidence from the corporate bond and medium-term note markets. *Journal of Finance* 50:1719–34.

Daves, Phillip R., and Michael C. Ehrhardt. 1993. Liquidity, reconstitution, and the value of U.S. Treasury strips. *Journal of Finance* 48:315–29.

Delianedis, Gordon, and Robert Geske. 2001. The components of corporate credit spreads: Default, recovery, tax, jumps, liquidity, and market factors. Finance Department Working Paper no. 22-01, University of California, Los Angeles, Finance Department.

Duffie, Darrell. 1996. Special repo rates. *Journal of Finance* 51:493–526.

Elton, Edwin J., and T. Clifton Green. 1998. Tax and liquidity effects in pricing government bonds. *Journal of Finance* 53:1533–62.

Fleming, Michael J. 2002. Are larger Treasury issues more liquid? Evidence from bill reopenings. *Journal of Money, Credit, and Banking* 34:707–35.

———. 2003. Measuring Treasury market liquidity. *Federal Reserve Bank of New York Economic Policy Review* 9:83–108.

Garbade, Kenneth D., and William L. Silber. 1979. Structural organization of secondary markets: Clearing frequency, dealer activity and liquidity risk. *Journal of Finance* 34:577–93.

Goldreich, David, Brend Hanke, and Purnendu Nath. 2003. The price of future liquidity: Time varying liquidity in the U.S. Treasury market. CEPR Discussion Paper no. 3900, Centre for Economic Policy Research, London.

Green, Richard C., and Brent A. Ødegaard. 1997. Are there tax effects in the relative pricing of U.S. government bonds? *Journal of Finance* 52:609–33.

Green, Richard C., and Kristian Rydqvist. 1997. The valuation of nonsystematic risks and the pricing of Swedish lottery bonds. *Review of Financial Studies* 2:447–80.

Grinblatt, Mark, and Narasimhan Jegadeesh. 1996. The relative pricing of Eurodollar futures and forward contracts. *Journal of Finance* 51:1499–1522.

Gwilym, Owain A. P., Lourdes Trevino, and Stephen Thomas. 2002. Bid-ask spreads and the liquidity of international bonds. *Journal of Fixed Income* 12:82–91.

Hamao, Yasushi, and Narasimhan Jegadeesh. 1998. An analysis of bidding in the Japanese government bond auctions. *Journal of Finance* 53:755–72.

Hess, Alan C., and Peter A. Frost. 1982. Tests for price effects of new issues of seasoned securities. *Journal of Finance* 37:11–25.

Jegadeesh, Narasimhan. 1993. Treasury auction bids and the Salomon squeeze. *Journal of Finance* 48:1403–19.

Jordan, Bradford D., and Susan D. Jordan. 1997. Special repo rates: An empirical analysis. *Journal of Finance* 52:2051–72.

Kamara, Avraham. 1988. Market trading structures and asset pricing: Evidence from the Treasury bill markets. *Review of Financial Studies* 1:357–75.

———. 1994. Liquidity, taxes, and short-term Treasury yields. *Journal of Financial and Quantitative Analysis* 29:403–17.

———. 1997. The relation between default-free interest rates and economic growth is stronger than you think. *Journal of Finance* 52:1681–94.

Kandel, Shmuel, Oded Sarig, and Avi Wohl. 1999. The demand for stocks: An analysis of IPO auctions. *Review of Financial Studies* 12:227–47.

Krishnamurthy, Arvind. 2002. The bond/old-bond spread. *Journal of Financial Economics* 66: 463–506.

Lippman, S. A., and J. J. McCall. 1986. An operational measure of liquidity. *American Economic Review* 76:43–55.

Longstaff, Francis A. 1995. How much can marketability affect security values? *Journal of Finance* 50:1767–74.

———. 2000a. Arbitrage and the expectations hypothesis. *Journal of Finance* 55:989–94.

———. 2000b. The term structure of very short-term rates: New evidence on the expectations hypothesis. *Journal of Financial Economics* 58:397–415.

———. 2001. Optimal portfolio choice and the valuation of illiquid securities. *Review of Financial Studies* 14:407–31.

———. 2004. The flight-to-liquidity premium in U.S. Treasury bond prices. *Journal of Business* 77:511–26.

Merton, Robert C. 1973. An intertemporal capital asset pricing model. *Econometrica* 41:867–88.

Nyborg, Kjell G., Rydqvist Kristian, and Suresh M. Sundaresan. 2002. Bidder behavior in multiunit auctions: Evidence from Swedish Treasury auctions. *Journal of Political Economy* 110: 394–424.

O'Hara, Maureen. 2003. Presidential address: Liquidity and price discovery. *Journal of Finance* 58:1335–54.

Silber, William. 1991. Discounts on restricted stock: The impact of illiquidity on stock prices. *Financial Analysts Journal* 47 (July–August): 60–64.

Simon, David P. 1991. Segmentation in the Treasury bill market: Evidence from cash management bills. *Journal of Financial and Quantitative Analysis* 26:97–108.

———. 1994. Further evidence on segmentation in the Treasury bill market. *Journal of Banking and Finance* 18:139–51.

Spindt, Paul A., and Richard W. Stolz. 1992. Are US Treasury bills underpriced in the primary market? *Journal of Banking and Finance* 16:891–908.

Strebulaev, Ilya. 2002. Liquidity and asset pricing: Evidence from the U.S. Treasury securities market. Unpublished manuscript, Institute of Finance and Accounting, London Business School, London.

Sundaresan, Suresh. 1994. An empirical analysis of U.S. Treasury auctions: Implications for auction and term structure theories. *Journal of Fixed Income* 4:35–50.

Warga, Arthur. 1992. Bond returns, liquidity, and missing data. *Journal of Financial and Quantitative Analysis* 27:605–17.