

THE NONTRADABILITY PREMIUM OF DERIVATIVES CONTRACTS

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ABSTRACT

We investigate a unique sample of nontradable Treasury derivatives that have identical tradable securities. The nontradability premium - the difference between the values of the nontradable and tradable assets - is statistically and economically significant. The premium covaries positively with interest rate volatility and relative tightness in the markets. The nontradability premium also increases as the tradable contract becomes more liquid. Our data overcome important shortcomings of U.S. Treasury data, offering almost-perfect laboratory conditions to study the determinants of liquidity. The premium covaries positively with the product of conditional interest rate volatility times the underlying bill's turnover. This product is a better liquidity measure than trading volume, amount outstanding, and turnover. A higher turnover is associated with a lower expected time to trade 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 E. Buffett
*“Berkshire Hathaway Inc., 2002 Annual Report”
(Chairman’s Letter, p. 13)*

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I. Introduction

The tradability of securities is an important determinant of their values and 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., Merton (1973) and Black and Scholes (1973)). Yet, the majority of derivatives contracts in the USA 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 re-trade before their expiration. The difficulty of financial institutions to liquidate assets and disengage 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

¹ According to the International Swaps and Derivatives Association, Inc. (ISDA) and the Bank for International Settlements (BIS), the notional amount outstanding of financial over-the-counter derivatives at the end of 2002 around the world was \$142 trillion, including \$102 trillion of interest rate derivatives (http://www.bis.org/publ/qtrpdf/r_qa0309.pdf#page=99).

² See, for example, 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 (in USA) and the International Accounting Standards Board (in UK) are currently studying how to value and account for nontradable employee stock options.

70 percent of the global over-the-counter derivatives market at the end of 2002

(http://www.bis.org/publ/qtrpdf/r_qa0309.pdf#page=99). 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 non-traded asset and its, otherwise identical, traded asset, however, has implication 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 non-traded is almost always ignored. Our results suggest that the differences between the equilibrium values of a non-traded 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

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

and Whitelaw (1993) study Japanese government securities; and Brenner, Eldor and Hauser (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 versus 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 foregoing the option to trade. We find that the nontradability premium is statistically and economically significant. The mean nontradability premium (annualized, net of transactions costs) during 1992-June 1997 is 0.38% (38 basis points) with a t-statistic of 16.31. Translating the differences in yields into differences in dollar income from holding the 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 increase their income by more than 7%.

Longstaff (1995) valuation model of the option to trade advances that the nontradability premium is a positive function of the price volatility and the time to expiration. The non-trading 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

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

considerable. Supporting Longstaff (1995), we find that the nontradability premium covaries positively with interest rate volatility.

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

There are many studies on the liquidity of US Treasury securities. They include, for example, 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 non-existent.⁵

⁵ Krishnamurthy (2002) and Goldreich, Hanke and Nath (2003) study the behavior of the 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 (April 2000) 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 (December 2000) shows that, in contrast to tests using rates on relatively less liquid Treasury bills, tests using rates on very liquid repo loans support the simple form of the expectations hypothesis in which term premiums are zero.

Our study makes a unique contribution to the study of the effects of liquidity on the values of fixed income securities because our 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 US 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 undeveloped. Traders were unable to short sell the nontradable contracts for future delivery and the Treasury bills in the secondary market. Consequently, counter-party risk of short positions should not affect the relative yields in our study. Second, relative prices of US 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, whether it is selling at a discount or a premium, and tax laws change frequently (see, for example, Green and Ødegaard (1997)). In contrast, as we discuss below, taxes should not affect the relative yields of the Israeli Treasury securities studied here. Third, unlike studies of liquidity differences in US futures and forward interest rate contracts (e.g., Kamara (1988) and 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

⁶ To buy or sell Treasury forward contracts in the USA 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 U.S. 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- 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.

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 thus offers an almost-perfect laboratory, which is typically not possible in the USA, to isolate the effects of tradability and liquidity on the prices of actual fixed income securities and their derivatives.

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

We find that the nontradability premium increases as the tradable contract becomes more liquid. In particular, the 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

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. Delianedis and Geske (2001), for example, find that liquidity risk and taxes are more important determinant of corporate credit spreads than default and recovery risk.

liquidity measure than 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.

The evidence regarding the relation between yield and size (amount outstanding) for US 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 curve is 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's (1991, 1994) and Fleming (2002) find that increases in a bill's supply leads to higher yields.⁸ Our evidence suggests that investors require a higher yield to hold a larger quantity of a particular bill, implying that demand curves for Israeli Treasury bills slope downward.

Lastly, 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, for the predictions of Boudoukh and Whitelaw (1993) regarding the effects of relative excess demands on the nontradability 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 paper 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

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

between the yields on the tradable and nontradable contracts, and advances the determinants of the premium. The empirical evidence is presented in Section IV. We conclude in Section V.

II. The Treasury bill markets in Israel

The markets for Treasury bills 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 CPI. 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 months bills were 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 to similar changes in the issuance of spot Treasury bills.)

The Treasury bill markets consist of the primary and secondary markets. In the primary market, the Bank of Israel offers Treasury bills and contracts for future delivery to the public, via auctions. In the secondary market Treasury bills trade on the Tel Aviv Stock Exchange (TASE) in call auctions, once a day. Table 1 provides data on the sizes of the different auctions and turnover on TASE. During the period under study, contracts for future delivery of 6-month and 12-month Treasury bills were offered. NIS 10 million of contracts for future delivery of Treasury bills were sold at each auction until 1994, and NIS 20 million per auction since 1995 (one \$US was between 2.2-3.5 NIS).

The contracts for future delivery of Treasury bills 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. The contracts also 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 of one-percent of the nominal value. This amount 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 USA in that they have a “clearing corporation” (the Bank of Israel), which eliminates the cost of default on the contracts. The contracts are different from futures contracts and similar to forward contracts in the USA, 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 USA (e.g. Kamara (1988) and 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 USA 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 USA and around the world are bilateral agreements among investors, which are very costly to re-trade before their expiration and usually impossible to short sell.

A. The Primary Market

In the period studied (1992–1997), 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, multi-bid, 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.⁹ Initially, the commercial banks dominated the trade in Treasury bills, holding about 60 percent of those sold in the TASE. Their market share declined to about 35 percent in recent years. Some 20 (of the 28) members of the TASE participate in the auctions for contracts for future delivery of Treasury bills on a regular basis. Each member transmits his instructions relating to his own portfolio and other institutions wishing to participate in the auction.

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 for future deliveries, and all auctions take place weekly at the same time, at 12:30 p.m. on Tuesdays. Members of the TASE transfer instructions via the Automatic Banking Services communications system. The auctions are discriminatory auctions where bidders submit competitive bid that consists of an interest rate (annual 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 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.¹⁰ Unlike the U.S. Treasury market, there is no forward (when-issued)

⁹ For comparison, the average bid-to-cover ratio for government securities is about 2.5 in the USA (Jegadeesh (1993) and Sundaresan (1994)) and Sweden (Nyborg, Rydqvist and Sundaresan (2002)), and 4 in Japan (Hamao and Jegadeesh (1998)).

¹⁰ While the bid-to-cover ratio always exceeded one in the US 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, Rydqvist and Sundaresan (2002).

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 US 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 USA is the residual left after the amount given to noncompetitive bidders including the Federal Reserve and foreign central banks.

B. The Secondary Market

Treasury bills trade on TASE. In 1992 turnover in Treasury bills was about NIS 11 Billion. Since then, the volume of trade in Treasury bills has grown constantly, and in 1997 the turnover reached NIS 22 Billion (see Table 1), which was more than \$5 billion. Treasury bills have terms of up to 12 months to maturity. Treasury bills are more liquid assets than Treasury bonds and most other financial assets in Israel.

During our sample period Treasury bills traded once a day on the TASE in a call auction method, which works as follows.¹¹ 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. Afterwards, the

¹¹ See Amihud, Mendelson and Lauterbach (1997) for a detailed description on the call auction trading method of TASE.

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 the same for all buyers and sellers. Once the 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 13:00 and 14:00. After 1995 the call auction became computerized, similar in structure to the previous multilateral one, and trading in Treasury bill took place at 15:30 every trading day.

It is important to note that there was no short selling of Treasury bills during our sample period. Kamara (1997) finds that relative spot US Treasury bill yields also contain a premium for the risk that short-sellers will default. Hence, because all the securities in our sample cannot be sold short and are guaranteed by the same institution – the Bank of Israel, differences in their yields should not reflect any credit risk.

It is also important to note that, according to our sources at 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 primary market’s 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*

Consider the following two riskless investment strategies for nine months. The first strategy consists of buying 9-month spot Treasury bills. The second consists of buying synthetic 9-month bills: a portfolio of long positions in 3-month spot Treasury bills and contracts for future delivery, 3 months later, of 6-month Treasury bills. The synthetic bill has the same characteristics as 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.

$\$F$ - The cost of buying, today, one contract for future delivery, 3 months later, of one 6-month Treasury bill.

Table 2 describes the cash flows on the two riskless investment strategies over the 9 months. A very important feature of the equivalent strategies in Table 2 is that they do not involve any short selling. This is important because investors were unable to short sell the Treasury bills and contracts for future delivery during our sample period. In addition, investors are tax-neutral between the strategies in Table 2. During our sample period there was no personal tax on any income from Treasury securities. Firms were taxed on all sources of “income” using the flat corporate tax rate. The tax treatment of income from the two investment strategies was thus identical (and incomes on each pair of tradable and nontradable contracts in our sample were recognized in the same tax period).

Table 2 shows that the current cost of buying the 9-month bill is $\$P_9$, and the current cost of buying the synthetic 9-month bill is $\$(F \times P_3)$, 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 re-trade 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 for the synthetic 9-month bill less than the amount they are willing to pay for the actual 9-month bill.

That is, in equilibrium,

$$(F \times P_3) < P_9 \tag{1}$$

Because we are focusing on the nontradable contract for future delivery let us re-write the Nontradability Premium Hypothesis as $F < (P_9 / P_3)$. The yield to maturity on a T-month Treasury bills with a current cost of P_T and a face value of \$1 is

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

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

$$(1 + f)^{\frac{6}{12}} > \frac{(1 + r_9)^{\frac{9}{12}}}{(1 + r_3)^{\frac{3}{12}}} . \tag{3}$$

Where r_3 , r_9 and f denote the yields to maturity of the 3-month bill, 9-month bill and the contract for future delivery.

The Nontradability Premium Hypothesis postulates that the difference,

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

is positive, in equilibrium, and is the extra yield that buyers of the

synthetic bill require to compensate them for the opportunity cost of foregoing the option to trade. We call this difference, the “nontradability premium.”

A dual way to look at this is as follows. The term $\frac{(1+r_9)^{\frac{9}{12}}}{(1+r_3)^{\frac{3}{12}}}$ 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.
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 for example, 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 is 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 spot bills, the tradable constituents of the nontradability premium. The first two pairs of variables are the trading volumes and amounts 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) and Kamara (1988, 1994)).

The fourth pair of variables we use to measure the liquidity of the tradable spot bills is the product of conditional interest rate volatility times each bill's turnover. Investigating US 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 either an increase in the liquidity of the spot bills market as a whole, or an increase in the liquidity of that specific bill

alone, or both.¹² An increase in the liquidity of both 9-month and 3-month bills due to an increase in the liquidity of the bill spot 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 yield and the nontradability premium.

Recall that the nontradability premium is $(1+f)^{\frac{6}{12}} - \frac{(1+r_9)^{\frac{9}{12}}}{(1+r_3)^{\frac{3}{12}}}$. A bill-specific increase

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 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 US 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

¹² The coefficient of correlation between the trading volumes of the 3-month and 9-month bills is only 0.23.

amount of bids divided by the amount of bids accepted) for the nontradable contract is almost 6.0 and the 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 contract for future delivery of 6-month Treasury bills, with about three 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, and ended in June 1997, when the Bank stopped issuing contracts for future delivery of 6-month Treasury bills. The sample covers the results of 285 weekly auctions.

We use the annualized yields to maturity on the contract for future delivery of 6-month Treasury bills, with about three months to delivery, and the exactly matching 9-month and 3-month spot bills. The data are collected once a week on Tuesdays – the day of the auctions in the primary market. The yield on the contract for future delivery is the average yield in the auction.

All yields are calculated net of the various trading costs for the securities. The subtracted costs include distribution fees, transaction costs and interest lost on margins.¹³

A. The Nontradability Premium

Table 3 reports the summary statistics for the annualized nontradability premium (net of transactions costs) during 1992-June 1997. The nontradability premium is economically and statistically significant. The mean premium over the entire sample is 0.38% (38 basis points) with a t-statistic of 16.31, and the median is 0.35%.¹⁴ Moreover, the premium is positive in 248 of the 285 observations (87%). Each of these three values is statistically significant at less than a 0.0001 level. The data also reveal that in the first two years of the sample the mean nontradability premium was 0.46%. Afterwards, the mean premium was around 0.31%.

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 increase their income by more than 7%. Longstaff (1995) valuation model of the option to trade advances that the nontradability premium is a positive function of the price

¹³ Participants in the auctions for contracts for future delivery must deposit a margin of one-percent of their successful bid. This deposit is returned to successful bidders at its face value. We add the interest lost on the deposit to the transaction costs. For example, successful bidders deposit in the Bank of Israel 0.29 percent of their allocation (1 percent, in annual terms, for 3 months from the date of the auction until the delivery date). Suppose that the relevant interest for this period was 14 percent. Then, the cost of lost interest for successful bidders is 0.04 percent.

¹⁴ 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 highest accepted bid yield, sometimes called the “stop-out” yield. Consequently, our estimated nontradability premium *understates* the true premium. We do not have data on “stop-out” yields.

volatility and the time to expiration. Thus, these premiums are considerable given that the non-trading 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 of the premium in Amihud and Mendelson (1991) and Kamara (1994) on illiquid short-term Treasury notes in the USA. It is, however, smaller than the effect of nontradability on stocks and options reported in Silber (1991) and Brenner, Eldor and Hauser (2001). Silber (1991) find that restricting the tradability of privately placed stocks leads to an average discount of 35% relative to otherwise identical registered stock. Brenner, Eldor and Hauser (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 two years, and the nontradable options in Brenner, Eldor and Hauser (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 non-synchronous quotes.¹⁵ The only way we can get some idea about the

¹⁵ 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

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 non-synchronous 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.¹⁶

We also investigated whether the uncertainty (or noise) due to non-synchronous 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. Lastly, we also repeated all the tests above using the

larger this ratio of excess demands, the lower the nontradable yield relative to the tradable yield. We will investigate this effect below.

¹⁶ 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.

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.¹⁷

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, 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 (one week) after our proxy for *relative* tightness had its highest value in our sample. Moreover, this value of 1.8 is much higher

¹⁷ Recall that we calculate the nontradability premium using the auction's average yield rather than the (higher) “stop-out” yield on the contract for future delivery. This biases our estimated premium. Moreover, 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 during that day. Hence, our tests also suggest that the any such bias is likely to be negligible and is not likely to have a statistically significant effect on time variation in our nontradability premium.

than the second highest value of 1.1 (the only other observation that is greater than one) and the average value of 0.3.¹⁸

Table 4 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.¹⁹ The regressions differ in that each regression uses different liquidity measures.

Consistent with option theory and 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 GARCH(1,1) process 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 auction theory and 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

¹⁸ The data reveal substantial increases in the demand for the contract for future delivery together with substantial declines in the demand for the spot bill, relative to previous weeks, in both the 2/23/1993 and 2/16/1993 auctions. This follows larger than usual amounts of 6-month bills auctioned by the Treasury in the preceding auctions. 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 by the Treasury in the preceding auctions.

¹⁹ For each of the regressions in the table, 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.

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 levels. The result is consistent with the 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 4 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-squared values were always higher when the regressions excluded liquidity variables for the 3-month bill, Table 4 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, and 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 the (the 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 amount outstanding data are for the Thursday following the auction. The reason is that although the amount outstanding data are collected two 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 a 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 (non-liquidity) explanation for this negative relation. Accordingly, the other regressions continue to include the amount outstanding variable *in addition* to other 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 preceding 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. The coefficient of the volatility times turnover proxy 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-squared and adjusted R-squared values in Table 4, and our conclusions regarding volatility and amount outstanding are unaffected. Thus, Table 4 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 option theory and Longstaff (1995).

Lastly, 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 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 bill 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 trading volume over amount outstanding. Trading volume and amount outstanding enter the first regression as separate variables, so that the negative (partial) coefficient of amount outstanding measures the effect of an increase in amount outstanding when trading volume is held constant. If, for amount outstanding, the turnover effect dominates the size effect, the partial coefficient of amount outstanding would be negative. Table 4 suggests, however, that this is not the reason why the coefficients of the amount outstanding of 9-month bill 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 the 9-month bill remains significantly negative (at less than 1%), with an estimated value of minus 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 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 US 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; and 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 elasticities.²⁰ 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 or 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 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 that we failed to fully control for, its partial coefficient should be positive. Hence, if the 9-month bills' demand function is horizontal, the effect of amount outstanding on the nontradability premium could not be negative. Consequently, our evidence that the partial coefficient of 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 be due to the fact that investors were not able to short sell Treasury bills in our sample period.

²⁰ Hess and Frost (1982) examine increases in the supplies of seasoned equity and do not reject the infinite price elasticity hypothesis. Kandel, Sarig, and Wohl (1999) find that demand schedules for Israeli IPOs are relatively 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.

V. Conclusions

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 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 USA often also reflect premiums for the risk that short-sellers will default, differential taxes, and cash flow differences 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 are not present in

the Israeli market. The Israeli Treasury bill market thus offers unique, almost perfect, laboratory conditions to study the factors affecting the value of 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 is 38 basis points.

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

While the nontradable contract is perfectly illiquid, the tradable contract is not a perfectly liquid security. We find that the nontradability premium increases as the tradable contract becomes more liquid. In particular, the nontradability premium is positively related to the product of the conditional interest rate volatility times the underlying bill's turnover. We 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.

Lastly, we find that investors require higher yields to hold greater quantities of particular bills. This suggests that the demand curves for Israeli Treasury bills are downward sloping.

References

- Amihud, Yakov and Haim Mendelson, 1986, "Asset pricing and the bid-asked spread," *Journal of Financial Economics*, 17, 223-249.
- Amihud, Yakov and Haim Mendelson, 1991, "Liquidity, maturity and the yields on U.S. government securities," *Journal of Finance*, 46, 1411-1426.
- 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, 365-390.
- Bikhchandani, Sushil and Chi-Fu Huang, 1993, "The economics of Treasury securities markets," *Journal of Economic Perspectives*, 7, 117-134.
- Black, Fischer and Myron Scholes, 1973, "The pricing of options and corporate liabilities," *Journal of Political Economy*, 81, 637-659.
- Boudoukh, Jacob and Robert F. Whitelaw, 1991, "The benchmark effect in the Japanese government bond market," *Journal of Fixed Income*, 1, 52-59.
- Boudoukh, Jacob and Robert F. Whitelaw, 1993, "Liquidity as a choice variable: A lesson from the Japanese government bond market," *Review of Financial Studies*, 6, 265-292.
- Brenner, Menachem, Rafael Eldor, and Shmuel Hauser, 2001, "The price of option's illiquidity," *Journal of Finance*, 56, 789-805.
- 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, 1719-1734.
- Daves, Phillip R., and Michael C. Ehrhardt, 1993, "Liquidity, reconstitution, and the value of U.S. Treasury Strips," *Journal of Finance*, 48, 315-329.
- Delianedis, Gordon, and Robert Geske, 2001, "The components of corporate credit spreads: Default, recovery, tax, jumps, liquidity, and market factors," Working paper 22-01, UCLA, Finance Department, December.
- 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, 1533-1562.
- Fleming, Michael J., 2002, "Are larger Treasury issues more liquid? Evidence from Bill reopenings," *Journal of Money, Credit, and Banking*, 34, 707-735.
- Fleming, Michael J., 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, 577-593.
- 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. London, Centre for Economic Policy Research.
- 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, 609-633.

Green, Richard C., and Kristian Rydqvist, 1997. "The valuation of nonsystematic risks and the pricing of Swedish lottery bonds," *Review of Financial Studies*, 2, 447-480.

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

Gwilym, Owain AP, 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, 755-772.

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, 1403-1419.

Kamara, Avraham, 1988, "Market trading structures and asset pricing: Evidence from the Treasury bill markets," *Review of Financial Studies*, 1, 357-375.

Kamara, Avraham, 1994, "Liquidity, taxes, and short-term Treasury yields," *Journal of Financial and Quantitative Analysis*, 29, 403-417.

Kamara, Avraham, 1997, "The relation between default-free interest rates and economic growth is stronger than you think," *Journal of Finance*, 52, 1681-1694.

Kandel, Shmuel, Oded Sarig, and Avi Wohl, 1999, "The demand for stocks: An analysis of IPO auctions," *Review of Financial Studies*, 12, 227-247.

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, 1767-1774.
- Longstaff, Francis A., April 2000, "Arbitrage and the expectations hypothesis," *Journal of Finance*, 55, 989-994.
- Longstaff, Francis A., December 2000, "The term structure of very short-term rates: New evidence on the expectations hypothesis," *Journal of Financial Economics*, 58, 397-415.
- Longstaff, Francis A., 2001, "Optimal portfolio choice and the valuation of illiquid securities," *Review of Financial Studies*, 14, 407-431.
- Longstaff, Francis A., 2004, "The flight-to-liquidity premium in U.S. Treasury bond prices," *Journal of Business*, forthcoming.
- Merton, Robert, C., 1973, "An intertemporal capital asset pricing model," *Econometrica*, 41, 867-888.
- Nyborg, Kjell G, Rydqvist, Kristian, and Sundaresan, Suresh M, 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, 1335-1354.
- 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.

- Simon, David, P., 1994. Further evidence on segmentation in the Treasury bill market, “*Journal of Banking and Finance*,” 18, 139-151.
- 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, London Business School (presented at the 2003 AFA program).
- 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, 605-617.

Table 1
Treasury bills: Total annual auctions and turnover, NIS Billions^{*}, 1992- 1997.

	Auctions for Treasury bills for immediate delivery			Auctions for Treasury bills for future delivery (3-4 months ahead)		Treasury bill turnover on TASE
	3 month	6 month	12 month	6 month	12 month	
1992	---	3.9	3.1	0.6	0.6	11.1
1993	---	4.1	3.9	0.6	0.6	10.6
1994	---	3.9	3.9	0.8	0.8	10.2
1995	2.4	7.1	7.2	1.0	1.0	18.1
1996	8.1	7.6	10.8	1.0	1.0	25.7
1997	14.0	4.4	15.2	0.5**	1.0	21.5

* - One \$US was between 2.2-3.5 NIS.

** - The data for the auction of contracts for future delivery of 6-month Treasury bills in 1997 are only for the period January-June.

Table 2
Costs, in dollars, of alternative ways of acquiring one 9-month Treasury bill.

Transactions on current date	Cost, in \$US		
	Today	After 3 months	After 9 months
<u>Direct strategy:</u>			
Buy one 9-month bill at a cost of $\$P_9$.	P_9	0	-1
<u>Synthetic strategy:</u>			
Buy F 3-month bills at a cost of $\$P_3$ per bill.	$F \times P_3$	$-F$	
Buy one contract for future delivery, 3 months later, of one 6-month bill for a cost of $\$F$.	0	F	-1
Total cost of Synthetic strategy	$F \times P_3$	0	-1

For simplicity, each cost already includes all the various trading costs including interest lost on margins.

Table 3
Sample statistics of the nontradability premium: Weekly, 1992-June 1997.

$$\text{The nontradability premium} = \left[1 + \left\langle \frac{6}{(1+f)^{12}} - \frac{\frac{9}{(1+r_9)^{12}}}{\frac{3}{(1+r_3)^{12}}} \right\rangle \right]^2 - 1, \quad \text{where } r_3, r_9 \text{ and } f \text{ are the}$$

annual yields to maturity of the 3-month Treasury bills, 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 transaction costs (including distribution fees and interest lost on margins). P-values under the means are based on the t-test. P-values under the medians are based on Wilcoxon test. P-values under the percent positive values are based on the sign test. The entire sample has 285 observations.

Period	Mean	Median	Standard deviation	Min	Max	Percent Positive
1992-1997	0.3786 (0.000)	0.3520 (0.000)	0.3918	-1.4164	1.5759	87.0% (0.000)
<u>Sub-periods</u>						
1992-1993	0.4632 (0.000)	0.4691 (0.000)	0.4486	-0.9700	1.5759	86.7% (0.000)
1994-1995	0.3127 (0.000)	0.2931 (0.000)	0.3836	-1.4164	1.5188	85.6% (0.000)
1996-1997	0.3158 (0.000)	0.3445 (0.000)	0.2886	-0.4527	1.2066	89.5% (0.000)
<u>P-values for tests of equality across sub-periods</u>						
All						
3 Sub-periods	0.016	0.003				
2 Sub-periods 1994-97	0.455	0.261				

Table 4

The determinants of the nontradability premium: Weekly, 1992-June 1997.

The exact calculation of the non-tradability premium (the dependent variable) is described in Table 3. The regressions differ in the variables used to capture time variation in liquidity. EXCESS DEMAND is excess demand in the auction of the contracts for future delivery divided by excess demand in the 6-month spot auction. OUTSTAND9M is the natural log of current week's outstanding amounts of 9-month spot bills. VOLATILITY is lagged interest rate volatility estimated as a GARCH(1,1) process. VOLUME9M is the natural log of previous week's trading volumes and current week's outstanding amounts of 9-month spot bills. TURNOVER9M is the previous week's turnover (defined as trading volume over amount outstanding) of 9-month spot bills. There are 285 observations. Heteroskedasticity-consistent p-values are in parentheses.

Variable	Regression Coefficient (p-value)		
Constant	2.0093 (0.0050)	1.9155 (0.0072)	1.8865 (0.0074)
VOLATILITY	0.6216 (0.0125)	0.6230 (0.0128)	0.5828 (0.0181)
EXCESS DEMAND	-0.2979 (0.0062)	-0.3123 (0.0032)	-0.3232 (0.0017)
OUTSTAND9M	-0.1194 (0.0016)	-0.0964 (0.0076)	-0.0943 (0.0087)
VOLUME9M	0.0278 (0.0988)		
TURNOVER9M		5.9266 (0.0853)	
VOLATILITY times TURNOVER9M			18.5475 (0.0281)
Nontradability premium(t-1)	0.2579 (0.0001)	0.2588 (0.0001)	0.2576 (0.0001)
Nontradability premium(t-2)	0.1804 (0.0067)	0.1758 (0.0090)	0.1746 (0.0090)
Nontradability premium(t-3)	0.1231 (0.0247)	0.1207 (0.0271)	0.1208 (0.0250)
R ²	0.2922	0.2913	0.2951
Adjusted R ²	0.2714	0.2705	0.2745

Figure 1. The nontradability premium, January 1992-June 1997.

