A Comparative Study of Canadian and U.S. Price Discovery In the Ten-Year Government Bond Market

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Abstract

This paper presents some new results on the price discovery process in both the Canadian and U.S. 10-year Government bond markets using high-frequency data not previously analyzed. We look at the relative information content of cash and futures prices in the market for Canadian Government bonds using futures transaction data supplied by the Montreal Exchange and OTC cash data reflecting transactions in the inter-dealer market that was supplied by CanPx. We also analyze similar data from the US market over a somewhat longer period using data on the cash market from GovPx in the first part of the study and subsequently from BrokerTec. To our knowledge, this is the first thorough study of price discovery using the BrokerTec data. Finally, an important feature of this paper is the comparative analysis of the evolution of the price discovery processes in Canada and the U.S. during the period (for which such data is available) 2002 through 2004.

With regard to the econometric methodology employed, we follow the information-share approaches introduced by Hasbrouck (1995) and Gonzalo-Granger (1995) building on the ideas of Booth *et al.* (1999) to evaluate the relative contributions of trading in the cash and futures markets to the price discovery process. Both approaches work in a vector error correction model that permits the separation of long-run price movements from short-run market microstructure effects. As well, in the spirit of Yan and Zivot (2004) we use impulse response functions to calculate size and temporal measures of market adjustment to equilibrium during the price discovery process.

In general, we find that price discovery occurs relatively more in the futures markets than the cash markets in both Canada and the U.S. and that the results look remarkably similar across the two countries despite the large differences in the sizes of their markets. Volatility in daily price discovery information shares is related in part to bid-ask spreads and trading volumes but there remains much unexplained.

1. Introduction

This paper presents some new results on the price discovery process in both the Canadian and U.S. 10-year Government bond market. On the one hand, the paper is a first look at some new high-frequency Canadian fixed-income data. During 2000, futures contracts on 10-year Government of Canada bonds were made available on an electronic platform at the Montreal Exchange. The development and evolution of the market for this instrument is of no small interest for the Canadian fixed-income market. Here we look at the relative information content of cash and futures prices in the market for Canadian Government bonds using futures data supplied by the Montreal Exchange and OTC cash data reflecting activity in the inter-dealer market that was supplied by CanPx. We have also analyzed similar data from the US market over a somewhat longer period. From January 2000 to the end of May 2001, spot-market data has originated from GovPx, and subsequent to April 2002 from BrokerTec. To our knowledge, this is the first thorough study of priced discovery using the BrokerTec data. Futures data originates with TickData, and covers January 2000 to the end of December 2004. Further details are given below. Finally, an important feature of this paper is the comparative analysis of the evolution of the price discovery processes in Canada and the U.S. during the period (for which data is available) 2002 through 2004 that represents the early maturing history of futures trading in the ten-year Government of Canada bond market. It also represents a period of important developments in U.S. markets with the introduction of electronic trading at the CBOT (July 2003) and strong growth in BrokerTec market share.

We follow the information-share approaches introduced by Hasbrouck (1995) and Gonzalo-Granger (1995) building on the ideas of Booth et al. (1999) to evaluate contributions of trading in the cash and futures markets to the price discovery process. Both approaches work in a vector error correction model that permits the separation of long-run price movements from short-run market microstructure effects. As well, we determine size and temporal measures of market adjustment to equilibrium during the price discovery process in the spirit of those introduced by Yan and Zivot (2004).

The paper is organized as follows. We present a brief review of the antecedent literature on price discovery in section one. Section two introduces the various markets considered in this study. We take particular care in describing the Canadian data given its novelty. Features of the underlying cash market, at least as revealed via inter-dealer transactions, are presented first. We then turn to a brief overview of the origin of the CGB market and its development since its inception in 1989. We end with a brief survey of the US data.

Section three surveys the econometric methodology employed in the paper. Section four presents the central empirical results of the paper. Price discovery measures are determined and compared for our two markets. The section also presents impulse-response comparisons for the two markets. Section five discusses the determinants of the information shares. Section 6 concludes.

2. Related Literature

Price discovery refers to the process through which financial markets converge on the efficient price of the underlying asset. Theoretically when two similar markets for the same product are faced with the same information arriving simultaneously, then the two markets should react at the same time in a similar fashion. When the two markets do not react at the same time, one market will then lead the other. When such a lead-lag relation appears, the leading market is viewed as contributing a price discovery function for that sector. Price discovery has been and continues to be an active field of research. The following researchers have looked at this question using a number of different cash and futures markets; in particular, Garbade and Silber (1982) looked at commodity futures, Stoll and Whaley (1990), Chan (1992) examined U.S. stock index futures, Grunbichler, Longstaff, and Schwartz (1994) studied German stock index futures, Poskitt (1999) has studied New Zealand interest rate futures, Upper and Werner (2002) examined German Bund Markets, and Mizrach and Neely (2005) for U.S. Government bond markets.

The general consensus in the price discovery literature is that the futures markets tend to lead the cash markets, the main reason advanced being the relatively lower transaction costs in the futures markets. There has emerged the trading cost hypothesis of price leadership that predicts that the market with the lowest overall trading cost will react most quickly to new information (see Fleming, Ostdiek, and Whaley, 1996). More recently, some studies have attempted to account for the differences in transaction costs and still show that the derivative markets tend to lead cash markets. There are some instances where the opposite relationship was found (Stephen and Whaley, 1990), who examine the price discovery relationship between options and stocks traded on the NYSE. Chan, Chung, and Johnson (1993) confirm these findings.

However, there are a number of factors involved in the measurement of lead-lag relationship which can bias the results. In particular, Garbade and Silber (1982) point out that the time of day when prices are surveyed can have an effect on the lead time one market has over the other. It appears that market prices exhibit a u-shaped pattern throughout the day with spreads the widest at the opening and closing of trading. In this paper, the authors analyze the relationship between the futures markets for a number of commodities and a cash equivalent price which is determined by removing the cost of carry from the observed future price. Once this cash equivalent price has been determined, a supply/demand schedule for both markets is developed. From this model, a measure of the importance of price discovery in the futures market relative to the cash market is computed. Garbade and Silber show that while futures markets dominate cash markets, cash prices do not merely echo future prices, there are reverse information flows from cash markets to future markets as well.

Using an ARMA framework, Grunbichler, Longstaff, and Schwartz (1994) show that when the underlying asset is floor traded and the future is electronically screen traded that futures prices lead spot prices by as much as 20 minutes. The findings are consistent with the hypothesis that screen trading accelerates the price discovery process. Tests using squared returns, to allow for a greater weight for large trades, also have similar results.

An important implication of the lead-lag relationship is that informed traders can act on their private information more rapidly and at a lower cost in the futures market than in the spot (see Stoll and Whaley, 1990, Stephan and Whaley, 1990). Future markets also provide greater immediacy (Grossman and Miller, 1988). If trading costs are lower, informed traders may find it possible to trade on the basis of less significant information. The effect would be to accelerate the price discovery of the futures market.

Finally, it should be noted that much of the previous research in price discovery has been conducted in markets where both the derivative product and the underlying have been traded in an open outcry fashion. There is evidence, in particular the research of Grunbichler *et al.* (1994), which shows that the use of an electronic trading platform in the futures market further increases the price discovery potential of the market.

As we have suggested, a number of different methodologies have been used to determine the time difference in the lead-lag relationship. In this paper, we will focus on the information share methodologies of Hasbrouck (1995) and Gonzalo and Granger (1995). Hasbrouck (1995) is based on the assumption of an efficient price common to both the futures and cash market and characterizes a market's contribution to price discovery - its information share - as the "proportion of the efficient price variation that can attributed to that market." (p. 1177.) Hasbrouck has argued that the appropriate econometric context for the analysis is supplied by the vector error correction model (Stock and Watson, 1988). Another approach is supplied by the identification of long-memory common factors suggested by Granger and Gonzalo (1995). The relative merits of the two approaches are the subject of some discussion; a special issue of the *Journal of Financial Markets* (2002) is devoted to the topic.

Harris, McInish, Shoesmith, and Wood (1995) build a vector error correction model of transaction price data on IBM stock prices across three spot markets. Prices are cointegrated across the three markets. By examining Granger causality tests and the size of the coefficients on the error correction term, they conclude that price adjustment occurs on all three markets in order to maintain cross-market equilibrium. Poskitt (1999) uses a similar framework to examine the sources of price discovery in cash and futures market for short-term interest rate contracts in New Zealand. The futures market is once again found to dominate the price discovery process even though it is a comparatively small-sized market.

Harris, McInish, and Wood (2002) expands on their earlier work using a Gonzalo and Granger (1995) framework to analyze the common factor weights attributable to three informationally-linked stock exchanges for 23 individual Dow stocks. They confirm Hasbrouck's (1995) results that the NYSE is informationally dominant in discovering the efficient price of the stock. They do, however, discover time variation in the share of price discovery attributed to the NYSE and explain this with a negative relationship between the price discovery share and spreads on the markets. The market with the lower spreads or transaction costs tends to dominate the price discovery process.

Recent papers using a VECM methodology include Kim, Szakmary, and Schwarz (1999) and Hasbrouck (2003) who test the transaction costs hypothesis across U.S. stock index futures markets, and Booth, So, and Tse (1999) for the German equity market. Hasbrouck (2003) finds that, for the S&P 500 and Nasdaq-100 indexes, price discovery was dominated by the electronically-traded futures contracts.

A recent paper examining price discovery across markets by Yan and Zivot (2004) assesses the efficiency of price discovery by the magnitude of pricing errors given by impulse response functions of the reaction to a permanent shock to the efficient price. Their methodology is similar in spirit to Hasbrouck (2003) but takes it a step further to numerically measure deviations from the efficient price. They apply their methodology to the case of price discovery for the JPY/EUR exchange rate by comparing the prices in the direct trading market to the markets for indirect implied trading via USD/EUR and JPY/USD. They find that substantial price discovery occurs through the USD markets due to the much greater degree of liquidity available in these markets. The relative liquidity and lower transaction costs of the USD markets are conducive to the efficient assimilation of dispersed economy-wide information.

Upper and Wener (2002) is very much in the spirit of our contribution. They examine price discovery between the German Bund futures and spot markets during 1998. They find that between 67% and 81% (using the Hasbrouck methodology) or about 83% (using the Gonzalo-Granger methodology) of price discovery occurred in the futures market during the relatively normal times of the first half of 1998. However, during some of the more volatile periods in the second half of 1998, particularly around the time of the LTCM crisis, the share of price discovery of the spot market fell to near zero. They claim this is consistent with anecdotal evidence they have that during stress periods spot trading simply follows the futures markets.

Finally, a recent addition to the literature is Mizrach and Neely (2005) who use the Hasbrouck and Granger-Gonzalo information shares to investigate bivariate price discovery across different cash and futures markets for U.S. Government bonds of different maturities. An innovation in this paper is the study of price discovery in a system of futures and cash bond prices of different maturities. Using just the 10 year bond data, the cash market dominated price discovery from 1995 to 1999 with an information share above 50%. However, in 2000 the cash market information share dropped significantly and the futures market began to dominate price discovery. In the full specification combining different maturities, it was found that trading in the 5 year bond cash market at the 30 year bond futures market dominated price discovery.

We conclude this review of previous work on price discovery with the observation that ours is the first paper to investigate the price discovery process between the spot and futures market for the Government of Canada 10 year bond. This is a particularly interesting exercise given the futures contact for this bond is relatively new but exhibits a high degree of trading and low transactions costs. The Canadian example should also provide an interesting contrast to the much deeper more liquid U.S. markets.

3. The CGB and the Ten-Year Government of Canada Bond Market; Futures on the U.S. Bond Market

Canadian Data

The source for the spot market data for the Government of Canada 10-year bond is Moneyline Telerate's CanPx system. A detailed analysis of liquidity in this market can be found in D'Souza, Gaa, and Yang (2003). CanPx is a data service that consolidates and disseminates trade and quotation data submitted by Canada's fixed-income IDBs. Over the sample period, the four Canadian IDBs are Freedom International Brokerage Company, Prebon Yamane (Canada) Ltd., Shorcan Brokers Limited, and Tullett Liberty (Canada) Ltd. CanPx was introduced by the IDBs and securities dealers on August 20, 2001 with a view to enhancing the degree of transparency in the Government bond market. Although in operation since 2001, there are two large breaks in the sample, from September 2001 to February 2002 and from March to September 2003. The sample used for this paper covers the period from February 26, 2002 to February 25, 2003 and November 27, 2003 to February 27, 2004.

Quotes posted at an IDB are firm commitments to trade at the specified price. The volume, however, can be 'worked up' through negotiations between the buyer and seller once a trade is initiated. The CanPx data amalgamates all the trade and quote data presented on the screens of the four IDBs from approximately 0700 to 1800 each day. Only the best bid and offer quotes from across the four IDBs are presented to CanPx customers and stored. Each line in the source data is a "snapshot" of the information on the CanPx screens for a particular security at a given time. A line of data is saved for each security every time there is a change anywhere on the CanPx screen so there is a significant amount of duplicate information. The data also contains some data entry errors that were filtered prior to use. In particular, while the IDB quotes are firm, there can be coding errors by the dealers for which they are not held accountable. For example, if a price is entered as 110 when it should have been 101, the dealer is only held to the cents and not the dollars. These errors are short-lived, quite obvious, and so were corrected. There were a few other data anomalies that could not be explained or corrected so these days were dropped from the estimation. In addition, there were a few periods of CanPx inactivity probably explained by occasional down times in their system. Any day with a period exceeding two hours with no price changes, while the futures market was still adjusting, was also excluded.

Roughly 55% of the Canadian secondary spot market was customer-dealer trade in 2002, while 46% was inter-dealer trading. Of the inter-dealer trading, 86% was through IDBs with the remainder being direct dealer to dealer trade. The CanPx data is relatively complete in that it records the best bid and offer quotes and all trades from all four of the Canadian IDBs. The CanPx data set, however, does not include data for the Canadian IDB "roll" market in which dealers trade one security for another on a spread basis. This is potentially an important part of the inter-dealer bond market but is believed to be more significant for treasury bills than for bonds.

In September 1989, the Montreal Exchange introduced a futures contract on the Ten-Year Government of Canada Bond to trade under the ticker symbol CGB. At any given time there are up to eight contracts available for trading corresponding to four maturity dates per year over two years. The vast majority of trading volume takes place on the front-month contract. Trading in the next-to-deliver contract usually increases only after the first notice day for the currently traded contract. In this study we have rolled over contract maturities when volume on the next to deliver contract surpasses the volume on the front month contract.

From the inception of the security until 2003 there appear to have been three distinct sub-periods in the trading history of the CGB. Until 1994 or so, the number of monthly contracts hovered about 50,000. Throughout the second half of the nineties the monthly figure hovered around the 100,000 figure, while in the more recent period the numbered climbed to 250,000. However, even with such growth the CGB trails a number of competing products from other exchanges including the Eurobund, the U.S. Ten-Year Treasury Note future, and the Long Gilt. The size of these markets relative to that for the CGB is considerable: the market volume of the Ten-Year Treasury Note futures is some 70 times larger, the Eurobund is again twice as large.

In September 2000, the Montreal Exchange moved from a traditional open outcry system to an automated electronic system, known as the Montreal Automated System (SAM). The move toward an electronic system follows a trend involving many of the other future exchanges around the world, particularly in Europe with both EUREX and LIFFE exchanges adopting an electronic platform. In Montreal, SAM represents the electronic order book where all orders submitted for trading are registered and matched. Intraday transactions for the CGB are available since October 22, 2001. This study only considers data from the daily continuous trading session that runs from 8:05 a.m. to 3:00 p.m., with three separate phases within this period. The first phase is the pre-opening phase from 8:05 a.m. to 8:18 a.m. when offers can be placed as well as cancelled. The second phase is the no cancel-phase from 8:18 a.m. to 8:20 a.m. during which orders can no longer be cancelled. The third phase covers the open continuous trading from 8:20 a.m. to 3:00 p.m. The data used in what follows is taken only from the no-cancel phase and the open continuous phase. In this data set, a recorded quote represents the best bid/offer spread at the time of recording and is maintained until a subsequent quote is entered.

Seven complete contracts fall within the purview of the Canadian portion of this study. In general, the trading days associated with a specific contract run until one to three days after the first notice of the contract. The cutoff is determined at the point where the volume for the next contract exceeds that of the current contract. All told there are 409 trading days in the sample.

US Data

There are two sources of spot market data for the U.S. Government 10-year bond. The first is GovPx, a consolidation service for the voice-brokered inter-dealer market. It was founded in 1990 by the dealer and inter-dealer broker community in response to concerns among government authorities that there was insufficient price transparency in the U.S. Treasury market. Quote and trade information from three inter-dealer brokers - Garban-Intercapital, Hilliard Farber, and Tullett & Tokyo Liberty – are combined into a single source that is marketed in real-time to fixed-income professionals. Only one major inter-dealer broker, Cantor Fitzgerald, is not a contributor, which is generally considered only to be a problem in the 30-year Treasury bond market. The data used in this study runs from January 2000 to the end of May 2001 in order to use the latest data possible, and because trading through GovPx brokers drops significantly beginning in 2001 quite possibly due to the advent of alternative electronic trading systems. Transaction price data is used to match the available futures data. The data is for the on-the-run bond.

Subsequent spot market data originates with BrokerTec, an inter-dealer electronic trading platform of secondary wholesale U.S. treasury bonds that currently has a market share of approximately 60-65% of the active issues. Its success since it opened for business in 2002 is one of the main reasons for the decline in trading reported through GovPx. It functions as a limit order book and operates from 7:00 pm until 5:30 pm EST the next day. Data on the full order book is available but only transactions prices will be used in this study to match data available from the futures market. The data is available from April 8, 2002 until December 31, 2004. Only data from the open hours of the futures pit will be used.

The U.S. futures data comes from TickData, a provider of high-quality cleaned data for research and analysis. The source of their data is primarily trading on the Chicago Board of Trade. Only transaction price data and volume is available. The data spans January 2000 to December 2004, with pre-July 2003 including only pit trading and subsequent trading after July 2003 including both pit and electronic trading. Pit trading is open from 8:20 am to 3:00 pm EST, while electronic trading runs from 8:00 pm one day to 5:00 pm the next day EST. Only data for the period from 8:20 – 3:00 when the pit is open is used. There are four contracts per year with maturities in March, June, September, and December; the same as in Canada. The data rolls from one contract to the next when daily trading on the 1st back contract surpasses trading on the front contract. Unfortunately, for trading pre-June 2003, transaction prices are only recorded at the minute. Starting in June 2003, the time of each transaction is recorded to the second.

Data availability prompts us to adopt the following framework for subsequent analysis.

		Contracts Studied	Days in Sample	Full Days in Sample
Contract 1	March 2000	GovPx Data; 60 sec	36	36
Contract 2	June 2000	GovPx Data; 60 sec	64	63
Contract 3	Sept 2000	GovPx Data; 60 sec	64	62
Contract 4	Dec 2000	GovPx Data; 60 sec	62	59
Contract 5	March 2001	GovPx Data; 60 sec	61	39
Contract 6	June 2001	GovPx Data; 60 sec	63	36
Contract 7	Sept 2001			
Contract 8	Dec 2001			
Contract 9	March 2002			
Contract 10	*June 2002*	BrokTec Data; 60 sec	37	36
		CanPx Data; 30 sec*	58	58
Contract 11	*Sept 2002*	BrokTec Data; 60 sec	63	62
		CanPx Data; 30 sec*	58	56
Contract 12	*Dec 2002*	BrokTec Data; 60 sec	61	58
		CanPx Data; 30 sec*	55	53
Contract 13	*March 2003*	BrokTec Data; 60 sec	61	56
		CanPx Data; 30 sec*	59	56
Contract 14	June 2003	BrokTec Data; 60 sec	64	62
Contract 15	Sept 2003	BrokTec Data; 60 sec	64	63
		BrokTec Data; 30 sec	63	62
Contract 16	Dec 2003	BrokTec Data; 30/60 sec	60	57
Contract 17	*March 2004*	BrokTec Data; 30/60 sec	62	57
		CanPx Data; 30 sec*	57	55
Contract 18	*June 2004*	BrokTec Data; 30/60 sec	63	62
		CanPx Data; 30 sec*	62	60
Contract 19	*Sept 2004*	BrokTec Data; 30/60 sec	64	62
		CanPx Data; 30 sec*	60	57
Contract 20	Dec 2004	BrokTec Data; 30/60 sec	62	58
Contract 21	March 2005	BrokTec Data; 30/60 sec	23	21

A variety of remarks are in order.

- We have dropped half trading days or days for which there is significantly missing data from the sample, a decision that results in the difference between the number of days in the sample and the number of full days in the sample.
- Our original intention was to use the GovPx data to analyze Contracts 7, 8 and 9. But the number of Full Trading days for which such data is available is too small to warrant analysis; only 20, 2, 3 days are respectively available for these contracts. As indicated above, the lack of GovPx data is a reflection of the success of the BrokerTec trading platform. However, BrokerTec data is not available for these contracts.

- On the U.S. side, we have matched cash transactions with the available futures market data. Accordingly, the sampling frequency is at 60 seconds for the data on contracts prior to the June 2003 and at 30 seconds for the BrokerTec data subsequently. We investigate the impact on price-discovery measures of sampling at both frequencies in the second period.
- On the U.S. side, futures data is available only for transactions and so the analysis focuses on transaction prices.
- On the Canadian side, we were also confronted with issues relating to the choice of price variable and sampling frequency. For the comparative portion of the study, we determined to use quotes, more particularly the mid-point of the bid-ask spread, rather than transaction prices as the fundamental variable to be modeled. There are considerably more frequent price updates throughout the day with this choice and hence we were more comfortable as a result in making the second decision to sample the data at 30-second intervals. We preferred to sample at the highest frequency possible consistent with sufficient price movement so that it would not seem that prices in one market or the other were not moving.
- We estimate daily price-discovery measures, and average these statistics over the contract.
- There are 800 observations per day using a 30-second clock and 400 using the 60-second clock.
- The contracts that are common to both the Canadian and U.S. data sets are italicized.

3. Price Discovery Across Markets

Both the Hasbrouck and Gonzalo-Granger approaches to price discovery feature a decomposition of price movements into a permanent, non-stationary component and a transitory component. Although ultimately related, the two approaches differ on how the permanent component is identified. On the Hasbrouck approach, the permanent component is a martingale and accordingly reflects features of efficient market behaviour. By contrast, the non-stationary component on the other approach may be forecastable. Our business is not to pronounce on the relative merits of the two approaches. There appears to be some consensus in the literature that both are useful. Here we outline the bare bones of the two approaches. For further details on these specifications, it should be noted that a recent issue of the *Journal of Financial Markets (2002)* assesses the two approaches in some detail.

From our perspective of a futures and spot market, the point of departure is a bivariate price process p_t given by the vector error correction model that reflects the reality that the two prices are related via arbitrage considerations:

$$(1) \qquad \Delta p_t \quad = \quad A p_{t-1} + \sum\nolimits_j B_j \, \Delta p_{t-j} + v_t \quad .$$

Given the cointegrating vector (1, -1) [since the difference between spot and futures prices should be 0 on average], the matrix $A = \begin{pmatrix} a_1 & -a_1 \\ a_2 & -a_2 \end{pmatrix}$. The adjustment coefficients a_1, a_2 figure prominently in what follows.

The Hasbrouck approach follows Stock and Watson (1988). After rewriting (1) in moving average form followed by some algebra, we determine an expression for the price level that has a permanent and transitory component:

$$(2) \qquad p_t \quad = \quad C(1)\sum\nolimits_{k=1}^{t} v_k + \tilde{C}(L) v_t + p_0 \quad ,$$

where C(L) gives the MA representation of the price difference process in (1) and $\tilde{C}(L)$ is a lag polynomial constructed from C(L). C(1) has identical rows c = (c_1, c_2) in the bivariate case due to cointegration, and so the permanent contribution of the innovation vector v_t to the price is cv_t with variance given by cVc', where V is the covariance matrix of v. If V is diagonal, the relative contributions of the individual markets to the overall variance can be isolated as:

$$(3) \qquad I_j = \frac{c_j^2 \operatorname{var}(v_j)}{cVc'} \quad ; \; j = 1, 2 \; and \; V = \begin{pmatrix} v_1 & 0 \\ 0 & v_2 \end{pmatrix} .$$

If V is not diagonal, then Hasbrouck proposes a Choleski factorization of V that allows a similar decomposition yielding information shares similar to the above procedure. However, here the attribution of information depends on the ordering of the variables preliminary to the decomposition. Each ordering in fact yields a different information share I_j for each market j; the range so determined is said to give the Hasbrouck bounds for the information shares.

It was established by Martens (1998) that the vector c can be determined from the A in the regression (1) and that this vector in turn is identical to the permanent component factors in the Gonzalo-Granger analysis discussed below. These factor weights are given by:

$$(4) \qquad w_1 = \frac{a_2}{a_2 - a_1} \quad \text{and} \quad w_2 = \frac{a_1}{a_1 - a_2} .$$

The Gonzalo-Granger approach views prices as determined as follows:

$$(5) \qquad p_t = W f_t + \tilde{p}_t ,$$

with f the non-stationary permanent component and $\tilde{p}$ the stationary transitory component. Identification is achieved by imposing two conditions including one that stipulates that that **f** is a linear combination of the current prices p .The factor weights are given by (4).

In short, the differences between the two approaches relate to the martingale feature of the Hasbrouck approach contrasted with the Gonzalo-Granger approach, and the fact that along with the weights associated with the error-correction adjustment the Hasbrouck approach considers as well the variances of the underlying innovations. These points are emphasized in Baillie *et al* (2002).

The Hasbrouck information share is bounded by [0,1] by construction. The GG measure sums to one across the two markets but is not necessarily bounded by the [0,1] interval. To ensure that the information shares are bounded by [0,1], we impose the restriction on the VECM that the loading on the error correction term in the futures equation must be less than or equal to zero while the loading on the error correction term in the cash equation must be greater than or equal to zero. This is consistent with the futures minus cash specification of the error correction term. In almost all cases, these restrictions were easily accepted.

Another manner in which price discovery has been studied recently is to examine the shape of the impulse response functions in each market following a shock. Hasbrouck (2003) performed visual inspections of the response functions to get a flavour for the speed of convergence across markets. Yan and Zivot (2004) formalized this methodology by computing the cumulative pricing errors during the price discovery process. Some preliminary technical remarks are in order.

According to this approach, we first compute the cumulative difference between the impulse response value in each period and the value to which it converges in the long-run. Since structural shocks are identified via Choleski decompositions, it follows that there are four impulse responses for each of two decompositions (two variables responding to two shocks according to two decompositions). Within each decomposition, the cumulative sums are then weighted by the share of the asymptotic variance decomposition for that market and shock (i.e., the futures market response to a cash market shock is weighted by the contribution of the cash market to futures market volatility in the long run). In turn, each Choleski decomposition is equally weighted. The result is a cumulative pricing error. Higher values of the error imply slower convergence to the new long-run equilibrium value following a shock. In other words, slower price discovery in that market.

In this paper we have used another statistic that perhaps gives a more realistic picture of the price convergence process than the cumulative pricing error in the previous impulse-response analysis. We determine, for each shock, the number of periods it takes the cash and futures market to return to equilibrium, or more precisely, to within a close approximation (10%) of equilibrium. The estimates for each impulse response were weighted in the same manner as above to yield an average number of periods until convergence. Accordingly, we then have a simple time measure of the relative efficiency of the two markets in processing new information.

4. Price Discovery: Empirical Results

Before estimation results for the VECM model of price discovery in the Canadian and U.S. markets are presented, perhaps a word or two on the evolution of the Canadian futures market [CGB] is in order given that this data has not been previously analyzed. We give considerable more detail in a companion paper (see Campbell, Chung, and Hendry, 2006)

The CGB market saw the average daily number of trades increase from about 540 trades for the June 2002 Contract to just over 950 trades in the September 2004 contract period. This represented a daily total volume increase from about 5250 contracts to 7300 contracts. The average daily trade size, however, fell from about 9.8 contracts to about 7.8 contracts. With a notional value of $100,000 per contract this implies an average trade size of less that $1 million and a total daily volume of over $700 million. In contrast, in the spot market in June 2002 there were only about 30 to 40 trades each day representing just over $160 million in total daily volume. The average daily trade size fell from about $4.7 million during the June 2002 Contract period to about $4.3 million during the September 2004 contract period. The inter-dealer spot market trading through IDBs has many fewer trades per day but each trade is much larger. The futures market is four to five times the size of the spot market considered here in terms of the value of daily volume traded.

The belief is that trading costs are generally lower on futures markets than on spot markets. Over the sample the spread has fallen in the CGB market from about 2.22 basis points in the June 2002 Contract to 1.40 basis points in the September 2004 Contract. At the same time, the spot market spread fell from 3.70 to 2.80 basis points. Both markets experienced reduced trading costs over the sample but, in each case, the CGB spreads were smaller by about 40% or more. This represents a potentially substantial savings for traders and a strong expectation for more price discovery in the futures market than in the spot market.

It should be stressed in passing that lower spreads in the futures market are a feature of the U. S. market as well.

We now turn to results for the Gonzalo-Granger and Hasbrouck information shares. As indicated in the previous section, we have dropped 14 days from the Canadian sample, 55 from the GovPx sample, 29 from the BrokerTec 60 second sample and 16 from the BrokerTec 30 second sample that correspond to half trading days, generally around Christmas, and days with insufficient trading data. Some of these days, but not all, give anomalous results and we decided to omit partial trading days from the sample, or days in which there is no significant price movement.

Information share results are reported in Table 1 for the CGB market. We should emphasize that we have imposed a co-integrating vector of (1, -1) in the estimation of equation (1). The EC terms are strongly significant across the samples. The cash market share is, of course, just one minus the CGB share. As described in the previous section, we consider three estimates of the information shares based on quote data sampled at 30- and 60- second frequencies and on trade data sampled at 30-second frequency. The information share numbers are daily averages over the life of the contract indicated.

The three information shares show that more than half of the price discovery for the 10-year bond occurs on the CGB futures market. According to the OLS results for quote data sampled at

30 seconds, the share for the futures market has risen from a minimum of 59% in Contract 10 to a high of 73% for Contract 17 according to the Granger-Gonzalo measure and remained close to 70% for all but the first contract. Indeed, the full sample estimate indicates that 69% of price discovery occurs in the futures market. The Hasbrouck measures track similar results. The Hasbrouck share has risen from the low-high range of 55%-72% in Contract 10 up to the range of 68%-80% for Contract 17. Overall, the Hasbrouck information share tends to yield a fairly tight range around a midpoint of the lower and upper bounds that is slightly larger than the results for the Granger-Gonzalo share. In sum, it appears that the information share of the futures market has settled around 70% in the Canadian market.

In this paper, we have undertaken considerable bootstrap analysis to assess the significance of the various information measures under consideration. The results reported in this version of the paper rely on standard bootstrapping procedures. We are also investigating the results using other re-sampling procedures such as the block bootstrap, the wild bootstrap, and bias corrected and accelerated confidence intervals.

The bootstrap results presented in Table 1 confirm the basic conclusion that well over half of price discovery occurs on the futures market. Here we see that, for the Gonzalo-Granger measure using quote data sampled at 30 seconds, almost 90% of the days have the futures market share of price discovery being greater than one-half, with the 90% bootstrap confidence interval for this information share greater than one-half on about 60% of the days. Similar results obtain for the e Hasbrouck lower bound: for 86% of the days the measure is greater than one-half and for 49% of the days the confidence interval for the Hasbrouck lower bound surpasses 0.5.

The plots in Figures 1a -1c give a day-by-day perspective on the Gonzalo-Granger numbers for the three Canadian measures. The graphs remind us that we have imposed the result that the Gonzalo-Granger bounds fall between 0 and 1 in the estimation procedure. An interesting feature revealed by the graphical presentation is the variability of the results over the contract and from contract to contract. The measures appear to be nicely behaved in Contract 17, while somewhat unruly in Contract 19. In the former, we see the quote-based measures bounded for the most part between 0.6 and 0.8 with less extreme variability than in the other contracts. Yet even in this contract the trade-based information share appears considerably more variable. These visual assessments are confirmed by the reported figures for standard deviation. Over the sample, standard deviation for the trade-based measure is 40% higher than for the quote measured sampled at 30 seconds. The quote measure based on 60 second sampling has intermediate variability tending more to that of the trade-based measure. For this reason, we prefer to use the quote measure sample at 30 seconds in the comparisons with the U.S. results to undertaken below.

Table 2 along with Figures 2, 3, 4 survey similar terrain for the U.S. price discovery process. If one passes directly to the Gonzalo-Granger results and the sample averages for the BrokerTec data over Contracts 15-21, the results appear similar result to the Canadian experience with a futures information share of 0.70. This average is somewhat lower than the average for the GovPx data over Contracts 1-6 and for earlier BrokerTec data over Contracts 10-14 where the futures information share is over 0.80. The number of days with information shares over one-half is high, although the lower bound of the confidence interval is well below 0.5 for many days. Indeed, for only 28% of the days in Contracts 15-21 do the 90% confidence bands surpass 0.5 for the BrokerTec data sampled at 30 seconds. The situation in this regard for the BrokerTec data sampled at 60 seconds is worse. It should be noted that this feature is characteristic of the last part of the sample. The GovPx data show information shares of 0.85 with over 90% of the days having shares greater than 0.5 with confidence intervals on average well above 0.5. Here the Hasbrouck bounds are relatively tight having [0.82, 0.94] as the average over the first 6 contracts. However, the Hasbrouck bounds for the subsequent contracts appear to grow progressively wider; the average for the BrokerTec 30 second data over the last 7 contracts is [0.44, 0.90] with the BrokerTec 60 second data wider still. Returning to the Gonzalo-Granger futures' share, it should also be observed that the bootstrap confidence intervals encompass 0.50 in many instances; over 80% of the time for days in the last three contracts for the BrokerTec data.

One other point worth noting comes from an examination of the contract by contract time series of the information shares. For the GovPx and BrokerTec 60 second results, the futures market information share is relatively stable from one contract to the next. There is some volatility but no clear pattern. After Contract 15, however, there is a clear drop in the futures market information share from above 80% to below 70% in Contract 17 and after. This is a surprising result given that electronic trading of the futures contract at the CBOT began in July of 2003, the middle of Contract 15. Despite the huge jump in activity with the advent of electronic trading, it appears as if it was not enough to offset the ongoing development of BrokerTec. It is also possible that higher trade frequency on the futures market post-July 2003 makes a 30-second sample too infrequent. More in-depth analysis is definitely required to explain fully this recent decline in price discovery on the futures market.

The daily Gonzalo-Granger shares are depicted in Figures 2-4. Figure 2 presents the GovPx results. Here we see that the high averages for information share reflect the reality that for many days the share is estimated to be at 1 or greater; recall that an upper bound of 1 is imposed on the result. However, it can be observed that the estimated value is uniformly high with few estimates falling below 0.5. Figure 3 presents similar results for the BrokerTec Contracts 10-14. A share of 1 is imposed in many instances and the overall estimated values are well above 0.5 with only an infrequent day below 0.5. The variability appears to be somewhat more pronounced than that of the earlier contracts with estimation based on the GovPx data.

However, the variability of the Gonzalo-Granger share estimates over the last 7 contracts appears extreme indeed, as revealed in Figure 4 that presents a dramatic realization of the summary statistics presented in Table 2. Here we contrast visually share estimates based both on sampling frequencies of 60 and 30 seconds. As the figures reveal, both estimates move around a great deal throughout each of the contracts, with those based on 60 second appearing slightly more variable.

The results in Table 1 for the Canadian data and Table 2 for the U.S. data that relate to the same contracts have been extracted for comparison's sake in Table 3. The comparisons involve Canadian data sampled at 30 second frequencies with BrokerTec 60 second data over four contracts and BrokerTec data sampled at 30 seconds for the last three contracts. The Canadian Gonzalo-Granger share is stable around 0.70, whereas the U.S. counterpart is higher over the first four contracts and lower over the last three. The variability of the U.S. measures is uniformly higher over all contracts. With regard to the Hasbrouck bounds, the results are similar across the seven contracts: the Canadian bounds are tighter with greater lower bounds and lower upper bounds.

The next table presents results in the spirit of Yan and Zivot (1994). Table 4 strongly suggests that the cash market exhibits a substantially slower rate of convergence and price discovery than does the futures market. Here we measure the average number of 30-second periods needed to come within 10% of the long-run asymptotic value for the impulse response to shocks in the two markets. We can see in the third panel that the difference is positive across all contracts. For the Canadian data, it took on average some 5 minutes longer for the cash market to reach its new equilibrium over the first four contracts or some 80% longer than the futures contract; over the last three contracts it took 4 minutes or some 70% longer. For the U.S. data, the difference in the time taken is somewhat longer; some 7.5 minutes and 6 minutes over the two groups of contracts. We can conclude the speed of convergence of the futures market is superior to that of the cash market. However, a look at the bootstrap results that attempt to assess the statistical significance may give pause for the U.S. results. Whereas for the Canadian data the number of days for which the difference in the time of convergence is significant represents some 50% of the sample, the result for the U.S. data is only 9% for the first four contracts and 13% for the last three.

It cannot be said that the U.S results are satisfying. The Gonzalo-Granger measure of price discovery is highly variable. The Hasbrouck bounds are quite wide. The significance of error correction terms in the VECM is low. These results contrast sharply with the Canadian results, a somewhat surprising outcome given the greater depth of the U.S. market and the relative immaturity of the Canadian.

5. The Determinants of Information Shares

Table 5 presents the results of regressions that attempt to explain daily movements in the Gonzalo-Granger futures information-share measure in terms of specific market features such as spread and trade data for the cash and futures markets. These include *Mean-Half Spread* for both cash and futures, a *Spread Ratio* measured as the futures spread divided by the sum of futures and cash spreads, and a *Pseudo Spread* variable computed from trade-by-trade data as the average price change from one trade to the next whenever there is a price change [for details, see Mizrach and Neely, 2006]. On the trade side, we include two variables indicating the number of trades in the cash and futures markets or a relative measure, *Trade Ratio*, computed in the same manner as for spreads. The trade and spread variables are standardized by their standard deviations. In addition, dummy variables are included for the first three days of the contract, the first ten days of the contract, and for Contracts 11 and 19.

Some comments on the results presented in Table 5:

- The signs on the spread variables in all the specification correspond to intuition (with the exception of one highly insignificant variable): when the spread widens in the futures market, there is a fall in the futures market share given trading likely switches to the cash market.
- The sign associated with the cash trading variable is not correct, and the impact of the number of trades in the futures market is imperceptible and insignificant.
- There is no significant difference between days of the week (not reported here) nor trends over the life of the contract other than what is reported. There are also no significant differences between macro announcement days and other days.[1]

[1] The U.S. results show some very low significance of an effect of FOMC minutes releases and Greenspan testimonies before Congress. Further analysis in future work is required to indentify properly whether price discovery information shares are different on days with macro news announcements and how these effects should be modeled.

- The negative sign on the dummy associated with the first three days of the Canadian specifications is consistent with the pictures in Figure 1. That the information share is lower for the first ten days of the U.S. specifications is perhaps surprising given the greater depth known to exist in the U.S. market.
- The results appear to be more interesting for the Canadian market, at least as measured by R^2.

In general, we see that part of the day-to-day variation in the computed information shares is related to bid-ask spreads and the level of trading activity. There is, however, much that is unexplained and ongoing work will be needed to understand what drives price discovery.

6. Conclusions and Future Research

In sum, after considerable analysis involving the Canadian data we can conclude that around 70% of price discovery occurs on the futures market through trading of the CGB contract, notwithstanding its relatively recent arrival in the Canadian market. Indeed, we have some evidence that the market has quickly matured since the first contract studied. This outcome is certainly consistent with priors that the price discovery occurs on the market with the lower transaction costs.

The results concerning the U.S. market are somewhat surprising even disconcerting given the greater trading depth of this market and the relative immaturity of the Canadian market. The variability of the Gonzalo-Granger information share measure is striking on the one hand, while on the other the Hasbrouck bounds are quite wide and somewhat uninformative as to the relative importance of the cash and futures markets in the price discovery process. It strikes us that these results pose some interesting challenges that we intend to address in future work. These include in no particular conceptual order:

- whereas it may be appropriate to sample the Canadian data at 30 second intervals, this frequency may not be fine enough for the U.S. data. Price discovery for a market with such depth should be conducted perhaps with a ten-second clock, or even finer.
- the specification of the underlying vector error correction equation could be enriched. Other variables such as order flows, spreads, macro announcement dates could be included directly.
- the specification could reflect intraday seasonality in the volatility of price movements.
- share regressions could be estimated with a limited dependent variable technique given that information shares are bounded by [0,1].

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Table 1
Price Discovery Information Shares
Canadian Market

Contract Maturity		Information Share Gonzalo-Granger				Information Share Hasbrouck LB				Information Share Hasbrouck UB	
		Mean	Std.Dev.	Days > 0.5	Days C.I. > 0.5	Mean	Std.Dev.	Days > 0.5	Days C.I. > 0.5	Mean	Std.Dev.
June 2002 [10]	Quote 30 sec	0.59	0.163	0.74	0.36	0.63	0.210	0.78	0.26	0.72	0.199
	Quote 60 sec	0.59	0.175	0.69	0.28	0.55	0.219	0.60	0.10	0.74	0.194
	Trade 30 sec	0.57	0.201	0.59	0.16	0.72	0.196	0.86	0.28	0.76	0.182
Sept. 2002 [11]	Quote 30 sec	0.68	0.172	0.90	0.59	0.72	0.190	0.86	0.48	0.81	0.166
	Quote 60 sec	0.69	0.202	0.88	0.46	0.66	0.234	0.71	0.34	0.84	0.202
	Trade 30 sec	0.61	0.222	0.68	0.29	0.75	0.243	0.91	0.39	0.79	0.242
Dec. 2002 [12]	Quote 30 sec	0.71	0.181	0.82	0.71	0.75	0.202	0.85	0.65	0.84	0.171
	Quote 60 sec	0.70	0.229	0.83	0.57	0.66	0.255	0.74	0.38	0.84	0.226
	Trade 30 sec	0.63	0.223	0.77	0.33	0.79	0.227	0.90	0.48	0.82	0.221
March 2003 [13]	Quote 30 sec	0.71	0.156	0.95	0.61	0.75	0.174	0.92	0.44	0.84	0.143
	Quote 60 sec	0.70	0.212	0.91	0.45	0.66	0.233	0.79	0.21	0.84	0.224
	Trade 30 sec	0.71	0.254	0.87	0.46	0.84	0.250	0.94	0.57	0.86	0.246
March 2004 [17]	Quote 30 sec	0.73	0.138	0.96	0.74	0.76	0.138	0.96	0.65	0.86	0.112
	Quote 60 sec	0.73	0.199	0.95	0.65	0.68	0.201	0.89	0.27	0.88	0.196
	Trade 30 sec	0.65	0.232	0.76	0.45	0.80	0.219	0.93	0.56	0.84	0.217
June 2004 [18]	Quote 30 sec	0.70	0.147	0.94	0.66	0.73	0.171	0.85	0.48	0.84	0.129
	Quote 60 sec	0.70	0.207	0.88	0.53	0.66	0.229	0.82	0.30	0.85	0.206
	Trade 30 sec	0.69	0.236	0.83	0.40	0.80	0.229	0.92	0.53	0.84	0.224
Sept. 2004 [19]	Quote 30 sec	0.68	0.198	0.85	0.60	0.69	0.213	0.78	0.45	0.81	0.177
	Quote 60 sec	0.67	0.268	0.84	0.47	0.61	0.281	0.67	0.30	0.82	0.257
	Trade 30 sec	0.69	0.271	0.84	0.47	0.82	0.267	0.95	0.55	0.85	0.271
Full Sample	Quote 30 sec	0.69	0.170	0.88	0.61	0.72	0.191	0.86	0.49	0.82	0.164
	Quote 60 sec	0.68	0.216	0.85	0.49	0.64	0.238	0.74	0.27	0.82	0.217
	Trade 30 sec	0.65	0.237	0.76	0.36	0.79	0.234	0.92	0.48	0.82	0.230

Cotract numbers are given in [ ]. The reported statisics in the table for Mean and Standard Deviationare are averages of daily estimates over the contract. The Gonzalo-Granger numbers come from the estimation of equation (1). The Hasbrock bounds are described in the text. The third and seventh columns of numbers [Days > 0.5] give the proportio of days for which the price dscovery statistic is greater than 0.50. The adjacent columns indicates the proportion of days where 0.50 is less than the 90% bootstrap confidence interval for the statistic. Results are reported for futures quote data sampled at 30 and 60 seconds, and for trade data.

Table 2
Price Discovery Information Shares
US Market

Contract Maturity		Information Share Gonzalo-Granger				Information Share Hasbrouck LB				Information Share Hasbrouck UB	
		Mean	Std.Dev.	Days > 0.5	Days C.I. > 0.5	Mean	Std.Dev.	Days > 0.5	Days C.I. > 0.5	Mean	Std.Dev.
March 2000 [1]	GovPx	0.67	0.251	0.72	0.36	0.59	0.258	0.67	0.22	0.86	0.200
June 2000 [2]	GovPx	0.86	0.210	0.97	0.75	0.78	0.215	0.92	0.45	0.95	0.176
Sept. 2000 [3]	GovPx	0.89	0.209	0.98	0.81	0.89	0.202	0.98	0.76	0.97	0.184
Dec. 2000 [4]	GovPx	0.82	0.257	0.90	0.64	0.81	0.252	0.93	0.56	0.93	0.228
March 2001 [5]	GovPx	0.95	0.466	0.97	0.92	0.96	0.468	0.97	0.92	0.98	0.479
June 2001 [6]	GovPx	0.88	0.458	0.95	0.72	0.88	0.459	0.95	0.72	0.94	0.481
Contracts 1 - 6	GovPx	0.85	0.360	0.93	0.71	0.82	0.356	0.92	0.63	0.94	0.362
June 2002 [10]	Brok. Tec 60	0.75	0.259	0.83	0.47	0.52	0.246	0.61	0.08	0.92	0.180
Sept. 2002 [11]	Brok. Tec 60	0.85	0.204	0.97	0.53	0.56	0.189	0.69	0.10	0.96	0.142
Dec. 2002 [12]	Brok. Tec 60	0.83	0.315	0.86	0.47	0.50	0.237	0.55	0.05	0.90	0.287
March 2003 [13]	Brok. Tec 60	0.83	0.294	0.93	0.46	0.53	0.249	0.57	0.07	0.96	0.273
June 2003 [14]	Brok. Tec 60	0.82	0.250	0.89	0.26	0.44	0.182	0.39	0.02	0.95	0.183
Contracts 10 - 14	Brok. Tec 60	0.82	0.268	0.90	0.43	0.51	0.222	0.56	0.06	0.94	0.223
Sept. 2003 [15]	Brok. Tec 30	0.83	0.215	0.94	0.55	0.61	0.209	0.76	0.13	0.95	0.147
	Brok. Tec 60	0.82	0.255	0.86	0.27	0.43	0.204	0.35	0.02	0.95	0.150
Dec. 2003 [16]	Brok. Tec 30	0.79	0.279	0.89	0.42	0.52	0.212	0.60	0.02	0.94	0.230
	Brok. Tec 60	0.75	0.343	0.81	0.09	0.33	0.190	0.21	0.00	0.92	0.237
March 2004 [17]	Brok. Tec 30	0.69	0.288	0.78	0.26	0.44	0.244	0.40	0.07	0.90	0.276
	Brok. Tec 60	0.63	0.356	0.71	0.10	0.27	0.208	0.14	0.02	0.89	0.282
June 2004 [18]	Brok. Tec 30	0.65	0.260	0.66	0.15	0.38	0.214	0.34	0.00	0.87	0.182
	Brok. Tec 60	0.64	0.336	0.66	0.05	0.26	0.195	0.16	0.00	0.89	0.187
Sept. 2004 [19]	Brok. Tec 30	0.62	0.259	0.61	0.18	0.38	0.192	0.26	0.02	0.87	0.202
	Brok. Tec 60	0.69	0.328	0.68	0.13	0.30	0.196	0.13	0.02	0.91	0.200
Dec. 2004 [20]	Brok. Tec 30	0.64	0.284	0.72	0.17	0.35	0.177	0.21	0.00	0.87	0.251
	Brok. Tec 60	0.68	0.354	0.69	0.07	0.26	0.171	0.03	0.00	0.90	0.255
March 2005 [21]	Brok. Tec 30	0.66	0.311	0.62	0.10	0.37	0.209	0.19	0.00	0.88	0.282
	Brok. Tec 60	0.71	0.356	0.71	0.00	0.29	0.181	0.19	0.00	0.91	0.223
Contracts 15 - 21	Brok. Tec 30	0.70	0.278	0.76	0.28	0.44	0.228	0.41	0.04	0.90	0.221
	Brok. Tec 60	0.70	0.337	0.73	0.11	0.31	0.201	0.17	0.01	0.91	0.223

Cotract numbers are given in [ ]. The reported statisics in the table for Mean and Standard Deviationare are averages of daily estimates over the contract. The Gonzalo-Granger numbers come from the estimation of equation (1). The Hasbrock bounds are described in the text. The third and seventh columns of numbers [Days > 0.5] give the proportio of days for which the price dscovery statistic is greater than 0.50. The adjacent columns indicates the proportion of days where 0.50 is less than the 90% bootstrap confidence interval for the statistic.

Table 3
Price Discovery Information Shares
US - Canadian Cmparison

Contract Maturity		Information Share Gonzalo-Granger				Information Share Hasbrouck LB				Information Share Hasbrouck UB	
		Mean	Std.Dev.	Days > 0.5	Days C.I. > 0.5	Mean	Std.Dev.	Days > 0.5	Days C.I. > 0.5	Mean	Std.Dev.
June 2002 [10]	Can Quote 30	0.59	0.163	0.74	0.36	0.63	0.210	0.78	0.26	0.72	0.199
	Brok Tec 60	0.75	0.259	0.83	0.47	0.52	0.246	0.61	0.08	0.92	0.180
Sept. 2002 [11]	Can Quote 30	0.68	0.172	0.90	0.59	0.72	0.190	0.86	0.48	0.81	0.166
	Brok Tec 60	0.85	0.204	0.97	0.53	0.56	0.189	0.69	0.10	0.96	0.142
Dec. 2002 [12]	Can Quote 30	0.71	0.181	0.82	0.71	0.75	0.202	0.85	0.65	0.84	0.171
	Brok Tec 60	0.83	0.315	0.86	0.47	0.50	0.237	0.55	0.05	0.90	0.287
March 2003 [13]	Can Quote 30	0.71	0.156	0.95	0.61	0.75	0.174	0.92	0.44	0.84	0.143
	Brok Tec 60	0.83	0.294	0.93	0.46	0.53	0.249	0.57	0.07	0.96	0.273
Contracts 10 - 13	Can Quote 30	0.67	0.174	0.85	0.57	0.71	0.199	0.85	0.46	0.80	0.177
	Brok Tec 60	0.82	0.273	0.91	0.49	0.53	0.230	0.61	0.08	0.94	0.234
March 2004 [17]	Can Quote 30	0.73	0.138	0.96	0.74	0.76	0.138	0.96	0.65	0.86	0.112
	Brok Tec 30	0.69	0.288	0.78	0.26	0.44	0.244	0.40	0.07	0.90	0.276
June 2004 [18]	Can Quote 30	0.70	0.147	0.94	0.66	0.73	0.171	0.85	0.48	0.84	0.129
	Brok Tec 30	0.65	0.260	0.66	0.15	0.38	0.214	0.34	0.00	0.87	0.182
Sept. 2004 [19]	Can Quote 30	0.68	0.198	0.85	0.60	0.69	0.213	0.78	0.45	0.81	0.177
	Brok Tec 30	0.62	0.259	0.61	0.18	0.38	0.192	0.26	0.02	0.87	0.202
Contracts 17 - 19	Can Quote 30	0.70	0.163	0.92	0.66	0.73	0.179	0.87	0.53	0.84	0.143
	Brok Tec 30	0.65	0.268	0.68	0.19	0.40	0.217	0.33	0.03	0.88	0.223

Cotract numbers are given in [ ]. The reported statisics in the table for Mean and Standard Deviationare are averages of daily estimates over the contract. The Gonzalo-Granger numbers come from the estimation of equation (1). The Hasbrock bounds are described in the text. The third and seventh columns of numbers [Days > 0.5] give the proportio of days for which the price dscovery statistic is greater than 0.50. The adjacent columns indicates the proportion of days where 0.50 is less than the 90% bootstrap confidence interval for the statistic.

Table 4

Number of Thirty-Second Periods until Long-Run Equilibrium is Attained

Contract Maturity		Futures Market			Spot Market			Difference			% of Days of significant difference		
		5%	Mean	95%	5%	Mean	95%	5%	Mean	95%	Spot>Futures	Futures>Spot	No Difference
June 2002 [10]	Can Quote 30	15.57	17.87	18.35	20.81	23.62	23.47	3.32	5.75 [0.32]	7.06	0.28	0.07	0.66
	Brok Tec 60	7.87	9.79	31.51	15.59	41.70	41.262	-11.65	31.91 [3.26]	30.02	0.14	0	0.86
Sept. 2002 [11]	Can Quote 30	10.05	11.37	12.41	18.55	20.92	20.95	6.87	9.55 [0.84]	10.23	0.50	0.00	0.50
	Brok Tec 60	7.69	8.47	13.01	14.22	18.49	18.422	2.47	10.02 [1.18]	9.64	0.11	0.00	0.89
Dec. 2002 [12]	Can Quote 30	8.71	9.91	10.82	17.63	19.65	19.77	7.41	9.74 [0.98]	10.47	0.66	0.04	0.30
	Brok Tec 60	14.01	23.33	26.21	19.89	31.98	29.090	-2.32	8.65 [0.37]	11.15	0.02	0.00	0.98
March 2003 [13]	Can Quote 30	10.67	12.18	14.88	21.86	26.18	26.48	8.46	14.01 [1.15]	14.74	0.43	0.02	0.55
	Brok Tec 60	7.98	7.20	13.20	17.82	24.13	22.928	5.59	16.93 [2.36]	14.01	0.14	0.00	0.86
Contracts 10 - 13	Can Quote 30	na	12.91	na	na	22.86	na	na	9.96 [0.77]	na	0.46	0.03	0.51
	Brok Tec 60	na	12.42	na	na	27.61	na	na	15.19 [1.22]	na	0.09	0.00	0.91
March 2004 [17]	Can Quote 30	7.76	8.90	9.58	14.70	16.23	16.30	5.67	7.33 [0.82]	8.00	0.62	0.02	0.36
	Brok Tec 30	8.74	18.26	22.69	17.49	34.08	30.840	-0.29	15.81 [0.87]	19.44	0.14	0.00	0.86
June 2004 [18]	Can Quote 30	10.16	11.81	12.61	17.18	19.50	19.72	5.46	7.69 [0.65]	8.64	0.52	0.00	0.48
	Brok Tec 30	9.46	11.03	14.52	15.61	21.13	20.66	1.85	10.1 [0.92]	10.54	0.08	0.02	0.90
Sept. 2004 [19]	Can Quote 30	10.54	11.91	12.92	17.70	20.20	20.15	5.51	8.29 [0.70]	8.96	0.42	0.05	0.53
	Brok Tec 30	7.63	9.13	11.15	15.16	20.43	19.55	4.62	11.30	11.30	0.18	0.00	0.82
Contracts 17 - 19	Can Quote 30	na	10.91	na	na	18.69	na	na	7.77 [0.71]	na	0.52	0.02	0.46
	Brok Tec 30	na	12.66	na	na	24.96	na	na	12.31 [0.97]	na	0.13	0.01	0.86

The numbers are averages of daily estimates over the contract. They represent the average number of periods taken to come within 10% of the long-run asymptotic value for the im response. For each day, the results are average across all possible impulse responses: for each of two Choleski orderings there are four impulse responses representing each markets response to each markets' shock. Each Choleski ordering is equally weighted while within each ordering, the impulses are weighted by the asympototic variance decomposition val The square brackets in the third panel represent the difference of the two markets divided by the futures' mean.

Table 5
Regression Results using Futures Market Daily Information Shares

	Gonzalo-Granger									
	Can-30sec[1]	Can-30sec	Can-60sec[1]	Can-60sec	BrTec-60sec[2]	BrTec-60sec	Brtec-30sec[3]	Brtec-30sec	GovPx[4]	GovPx[4]
Constant	0.401	1.121	0.415	1.104	1.454	2.741	0.277	3.168	0.818	1.400
	7.502	11.098	6.864	9.741	4.333	6.257	0.803	5.850	14.637	7.092
First 3 Days	-0.159	-0.181	-0.129	-0.149						
	-3.910	-4.357	-2.800	-3.194						
First 10 Days					-0.089	-0.089	-0.046	-0.050		
					-3.007	-2.997	-1.386	-1.491		
Contracts #11, -#19	0.091	0.098	0.084	0.087						
	4.096	4.439	3.359	3.540						
Mean Half Spread-F	-0.048		-0.049							
	-4.175		-3.833							
Mean Half Spread-C	0.056		0.058							
	5.706		5.217							
Spread Ratio		-0.910		-0.905		-2.132		-2.696		-0.999
		-5.610		-4.976		-4.258		-4.605		-4.291
Pseudo Spread-F					-0.033		0.009		-12.651	
					-2.662		0.700		-4.169	
Pseudo Spread -C					0.055		0.042		4.804	
					4.454		3.375		3.549	
Number of Trades-F	0.006		0.004		-0.076		-0.011		0.00006	
	0.645		0.390		-3.603		-0.448		1.210	
Number of Trades-C	0.038		0.032		0.072		0.020		0.00049	
	4.224		3.138		3.513		1.024		1.644	
Trade Ratio		-0.299		-0.265		-0.286		-0.121		-0.095
		-3.588		-2.837		-4.258		-0.923		-0.620
RSQ	0.205	0.171	0.145	0.124	0.074	0.077	0.034	0.051	0.218	0.186

The spread and trade explanatory variables have been standardized. t-ratios are on the second row of each entry. For further details see text.

[1] There are 395 observations for the Canadian 30-sec and 60-sec results.

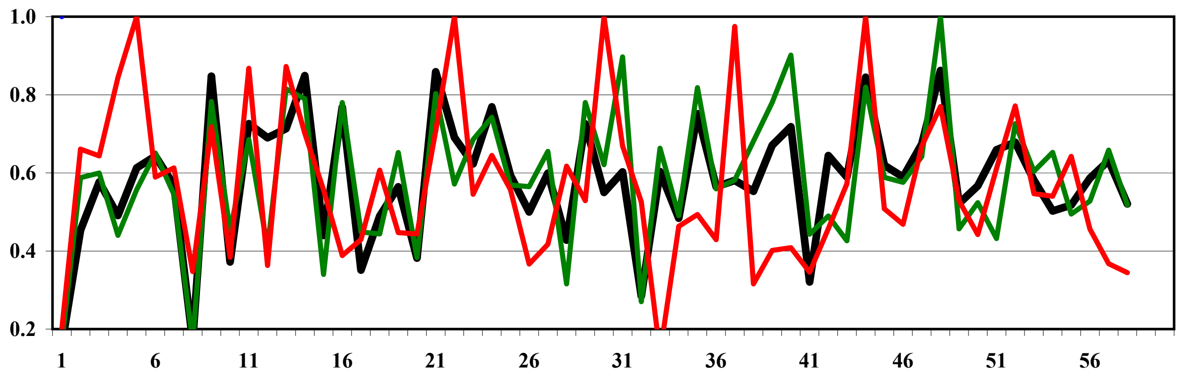
[2] There are 654 observations for the BrokerTec 60-sec results.

[3] There are 379 observations for the BrokerTec 30-sec results.

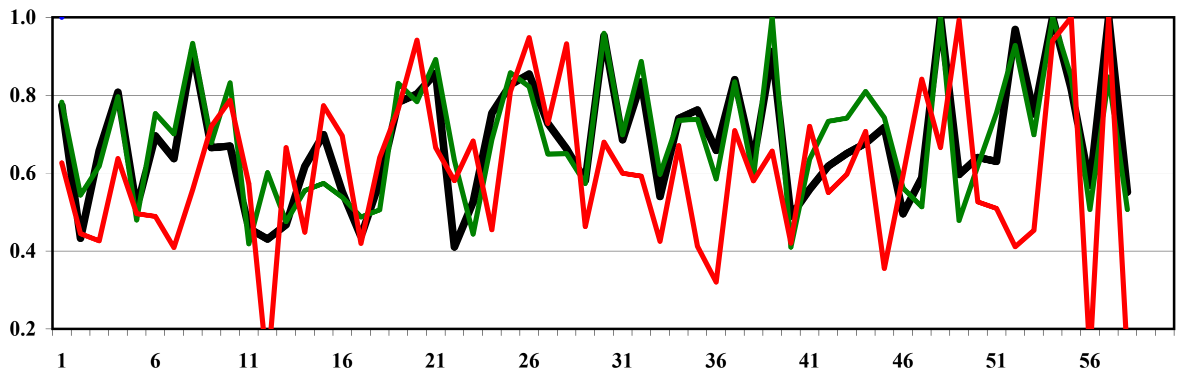
[4] There are 296 observations for the GovPx results.

Figure 1a
CGB Price Discovery Shares By Contract-OLS
Canada Quotes---30 sec Quotes--60 sec Trades --30 sec

June 2002 [contract 10]



Sept. 2002 [contract 11]



Dec. 2002 [contract 12]

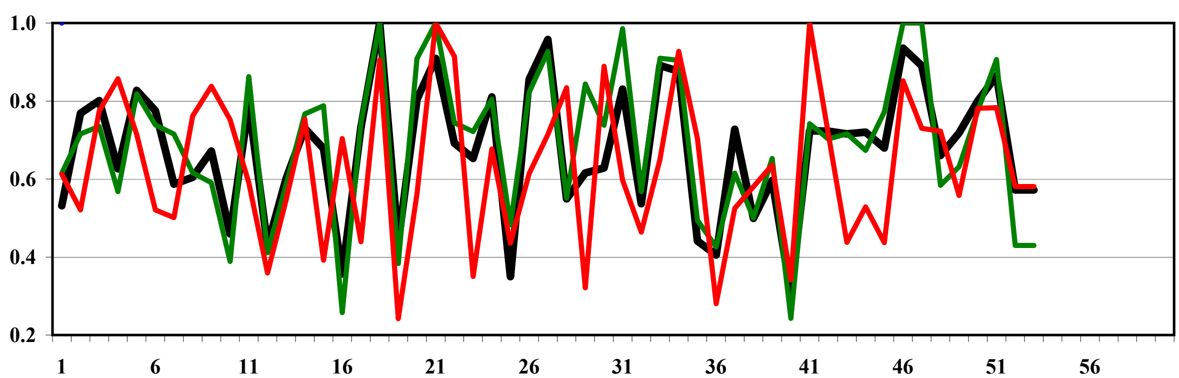
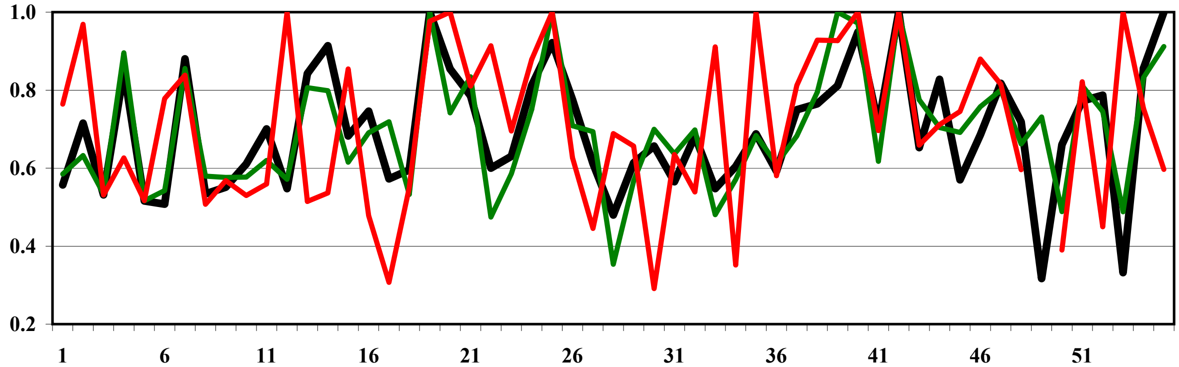


Figure 1b

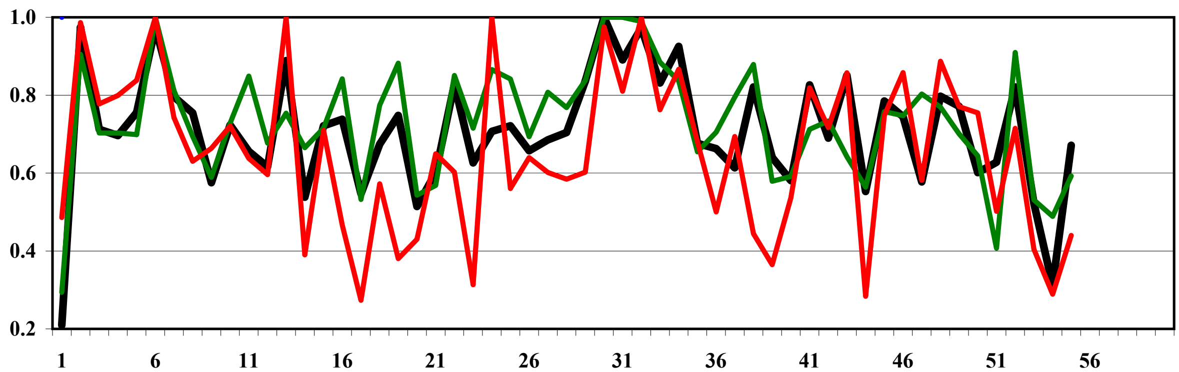
CGB Price Discovery Shares By Contract-OLS

Canada **Quotes---30 sec** **Quotes--60 sec** **Trades --30 sec**

March 2003 [contract 13]



March 2004 [contract 17]



June 2004 [contract 18]

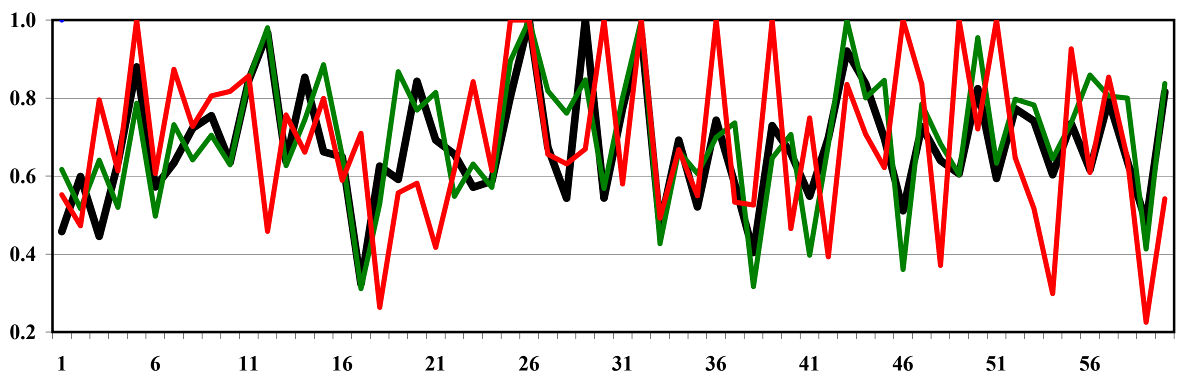


Figure 1c
CGB Price Discovery Shares By Contract-OLS
Canada Quotes---30 sec Quotes--60 sec Trades --30 sec

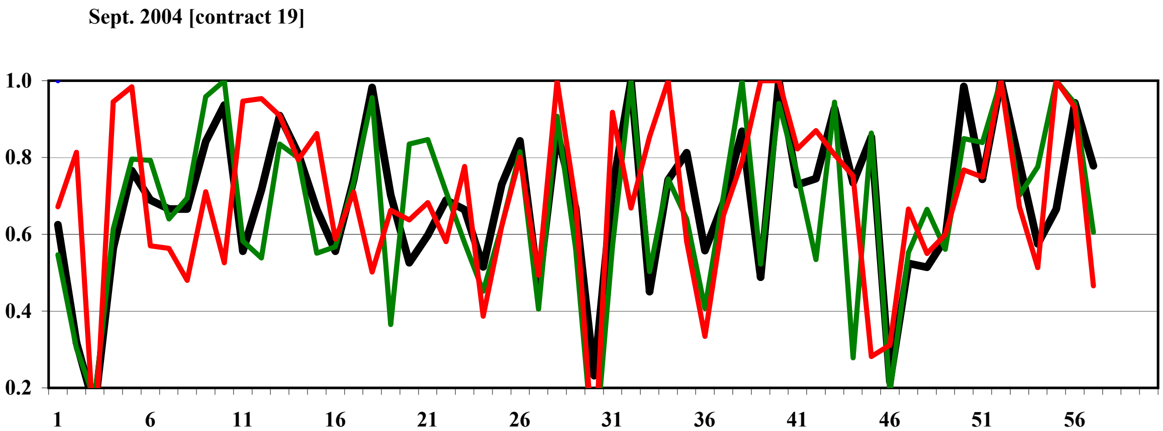


Figure 2
Price Discovery Shares By Contract-OLS
US GovPx Contracts 1-6

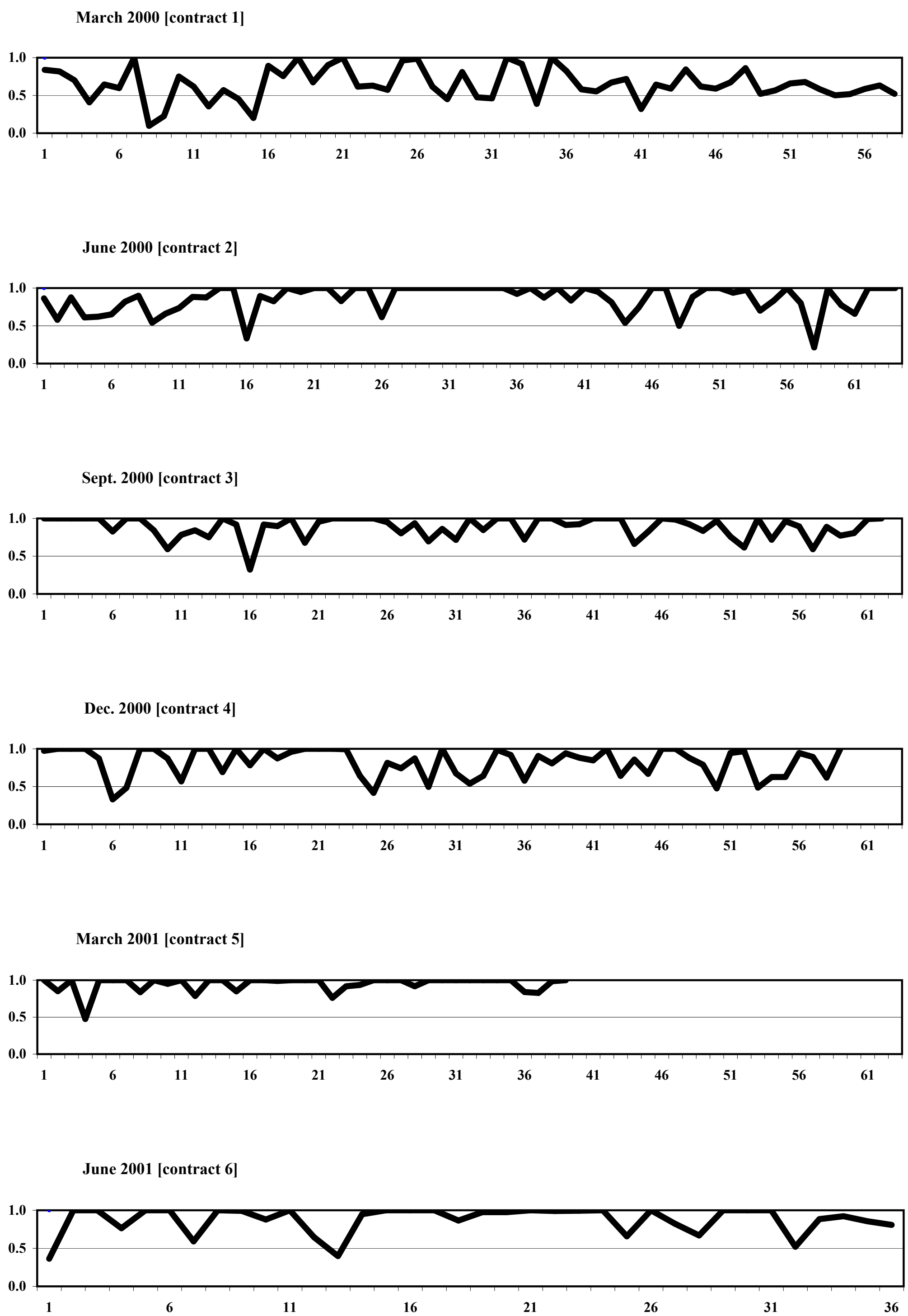
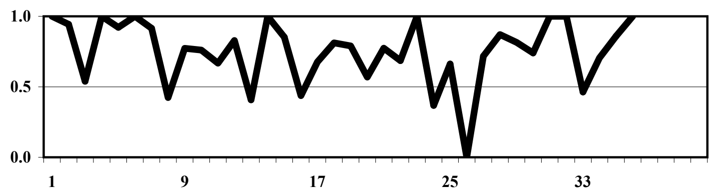
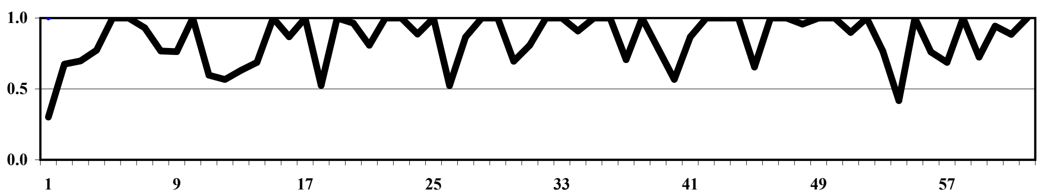


Figure 3
Price Discovery Shares By Contract-OLS
US BrokerTec-60sec Contracts 10 -14

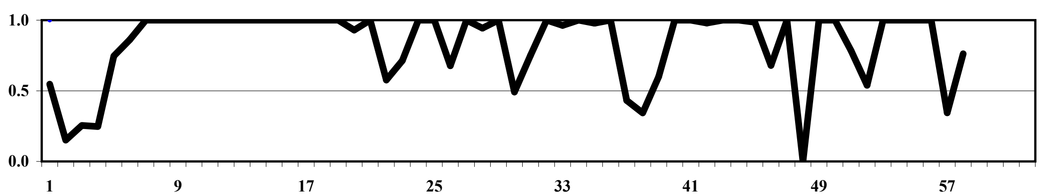
June 2002 [contract 10]



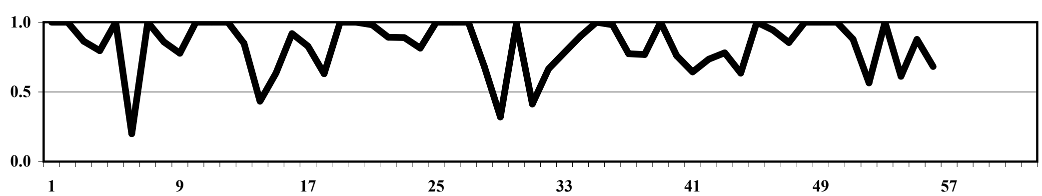
Sept. 2002 [contract 11]



Dec. 2002 [contract 12]



March 2003 [contract 13]



June 2003 [contract 14]

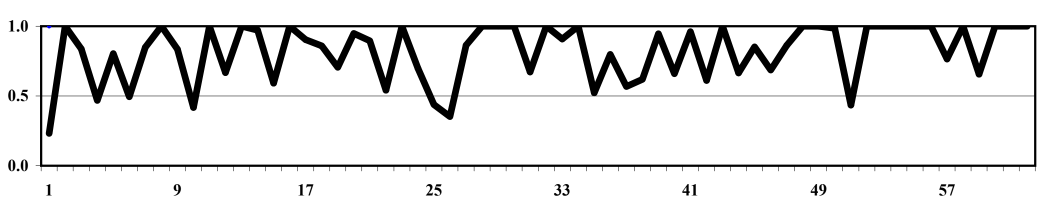
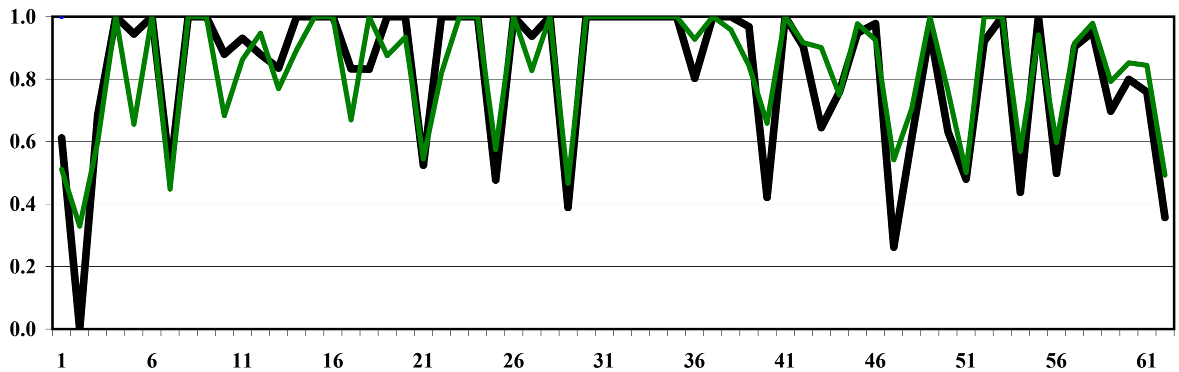
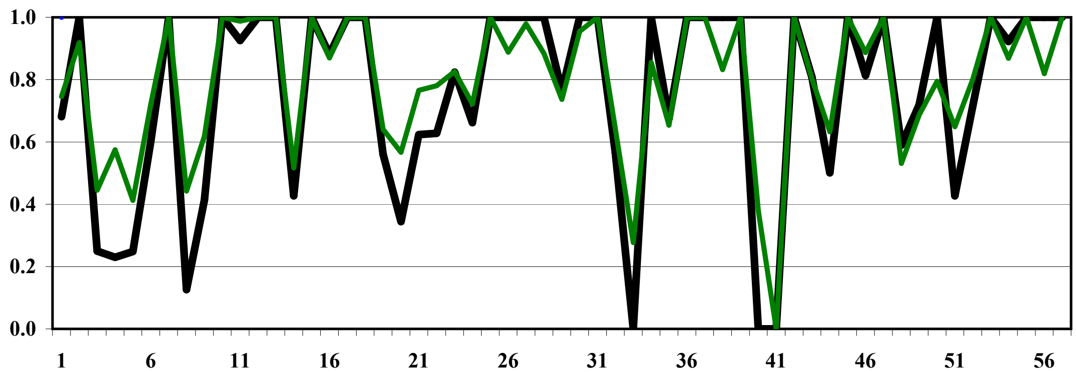


Figure 4a
Price Discovery Shares By Contract-OLS
US BrokerTec---60 sec BrokerTec--30 sec

Sept. 2003 [contract 15]



Dec. 2003 [contract 16]



March 2004 [contract 17]

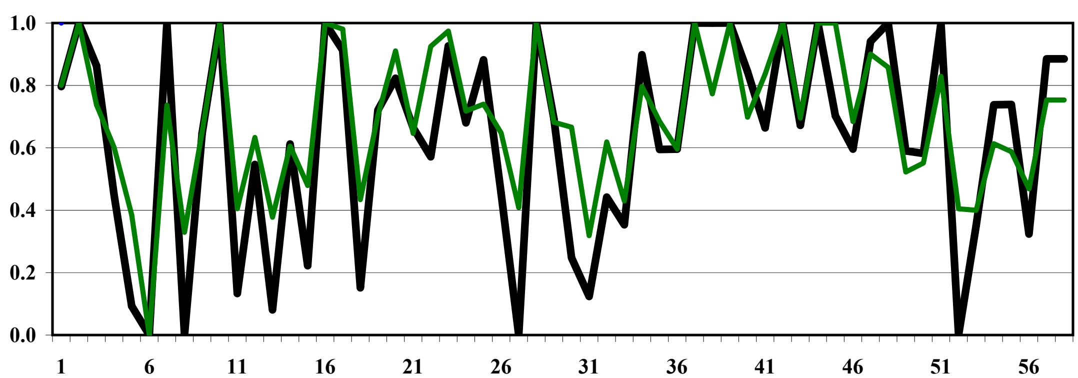
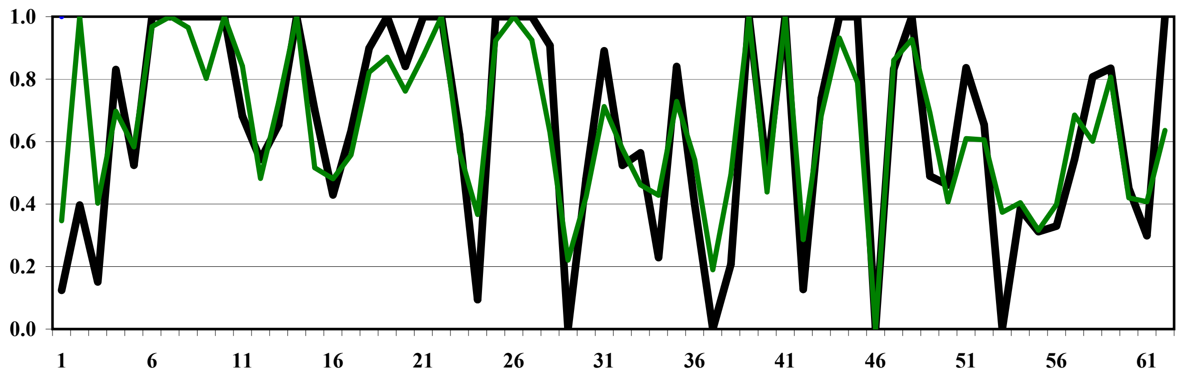
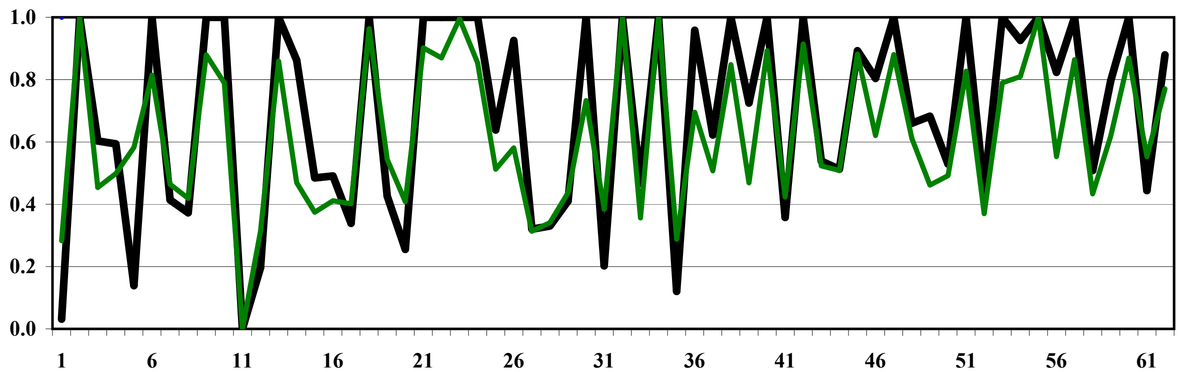


Figure 4b
Price Discovery Shares By Contract-OLS
US BrokerTec---60 sec BrokerTec--30 sec

June 2004 [contract 18]



Sept. 2004 [contract 19]



Dec. 2004 [contract 20]

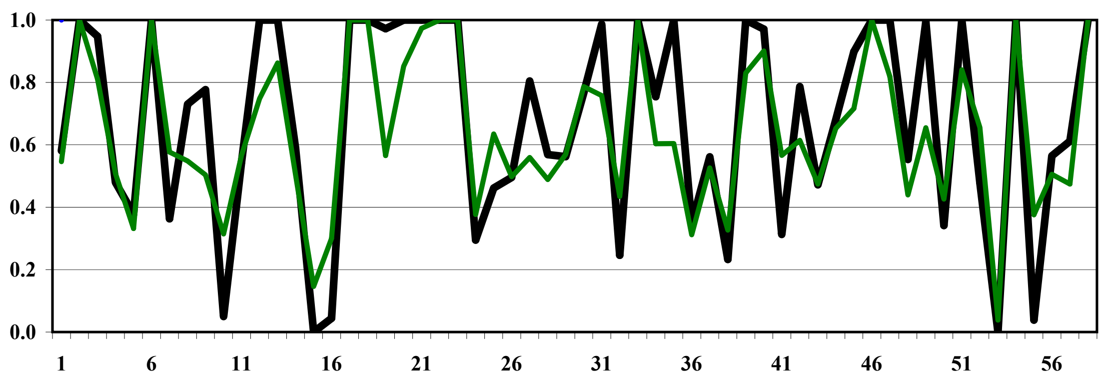


Figure 4c
Price Discovery Shares By Contract-OLS
US BrokerTec---60 sec BrokerTec--30 sec

March 2005 [contract 21]