BANK OF CANADA
BANQUE DU CANADA

Working Paper/Document de travail
2007-4

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Bank of Canada Working Paper 2007-4

February 2007

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ISSN 1701-9397

Acknowledgements

Comments from Greg Bauer, Chris D’Souza, Silvia Gonçalves, and Ingrid Lo are greatly appreciated. We thank seminar participants at the Bank of Canada and the 2005 Annual Meeting of the Northern Finance Association. We acknowledge the *Bourse de Montréal* and CanPx for providing their data on the CGB futures contract and spot market trading, respectively. Any remaining errors are our own.

Abstract

In this paper we look at the relative information content of cash and futures prices for Canadian Government bonds.

We follow the information-share approaches introduced by Hasbrouck (1995) and Harris et al (1995), applying the techniques in Gonzalo-Granger (1995), to evaluate the relative contributions of trading in the cash and futures markets to the price discovery process. Both approaches estimate a vector error correction model that permits the separation of long-run price movements from short-run market microstructure effects. As well, we follow Yan and Zivot (2004) who introduce size measures of a market's adjustment to a new equilibrium during the price discovery process. We find that, on an average day, just over 70% of price discovery occurs on the futures market where bid-ask spreads are lower and trading activity is higher. The size of the responses to shocks and the time taken to adjust to a new equilibrium are found to be significantly larger for the cash market.

JEL classification: G12, G13, G14
Bank classification: Financial markets; Market structure and pricing

Résumé

Les auteurs examinent les contenus informatifs respectifs des prix au comptant et à terme des obligations du gouvernement canadien.

Pour évaluer les contributions respectives des marchés au comptant et à terme au processus de découverte des prix, Chung, Campbell et Hendry recourent aux méthodes élaborées par Hasbrouck (1995) et par Harris et autres (1995), ces derniers s'inspirant des techniques qu'utilisent Gonzalo et Granger (1995). Les deux méthodes sont appliquées à un modèle vectoriel à corrections d'erreurs qui permet de distinguer les mouvements de prix à long terme des effets à court terme liés à la microstructure des marchés. En outre, dans l'esprit des travaux de Yan et Zivot (2004), les auteurs mesurent l'ampleur des déviations que le marché enregistre par rapport aux nouvelles valeurs d'équilibre durant le processus de découverte des prix. Ils constatent qu'au cours d'une journée ordinaire, le marché à terme, sur lequel les écarts acheteur-vendeur sont plus bas et l'activité est plus grande, contribue à hauteur d'un peu plus de 70 % à la découverte des prix. L'ampleur des réactions aux chocs et la vitesse de retour à l'équilibre sont nettement plus élevées sur le marché au comptant.

Classification JEL : G12, G13, G14
Classification de la Banque : Marchés financiers; Structure de marché et fixation des prix

1. Introduction

This paper is a first look at some new Canadian fixed-income data. In 2000, futures contracts on 10-year Government of Canada bonds began to be traded on an electronic platform at the Montreal Exchange. When combined with data from the OTC cash market data reflecting transactions in the inter-dealer market covered by CanPx, this represents a truly rich and unique data set that can be used to investigate price discovery in two markets that are very important to the Canadian financial system. It is important to have an understanding of the characteristics of the price discovery process to identify any possible inefficiencies that exist.

With regard to the econometric methodology employed, we follow two methodologies for calculating a market's contribution to the price discovery process. The first technique for computing information shares was introduced by Hasbrouck (1995) while the second was contributed by Harris et al (1995), applying the techniques in Gonzalo-Granger (1995). Each technique is used to evaluate the contributions of trading in the cash and futures markets for government debt 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 based on a methodology introduced by Yan and Zivot (2004).

There are several contributions in this paper. The first is that this is the first study to compute measures of price discovery across multiple markets using Canadian fixed-income data. Little has been done to examine price discovery in bond markets in comparison to a large literature that has compared price discovery across various equity markets. Another contribution of the paper is that alternative estimation techniques are employed in an attempt to account for some important heteroskedasticity that exists in the data. A GARCH model with intra-day seasonal effects and another model that uses only data from the beginning of the day are fit to the data and also used to compute information shares as part of a robustness check of the results. The third important contribution of the paper is that information shares are computed on a daily basis and then related to characteristics of the markets to show and explain how price discovery changes over time. Finally, bootstrap confidence bands are generated for all of the information shares and impulse response statistics to lend added support to the conclusions.

The various estimates reveal that about 70% of price discovery occurs on the futures market for the ten-year Government of Canada bond. The CGB market is an electronic exchange-traded customer market with lower bid/ask spreads than the inter-dealer voice-brokered spot market, which is found to be an important determinant of the day-to-day movements in the information share. Using the alternative GARCH model to account for some of the heteroskedasticity that is present yields an only slightly smaller estimate of the information share of the futures market. Measures of the cumulative deviation of each market following a shock and the amount of time it took to respond to a shock showed that the spot market took significantly longer to adjust to a new fundamental price. In sum, significantly more price discovery occurs via the futures market for the ten-year Government of Canada bond than through the spot market. This result is in line with observations in other bond and equity markets.

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 two markets considered in this study. Features of the underlying cash market, at least as revealed via inter-dealer transactions covered by CanPx, 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, and subsequently consider some comparative summary statistics for these two markets for the contracts studied in this paper. In this section, we take particular care to describe how the transaction data have been filtered for use in the empirical analysis that follows. Section three surveys the econometric methodology employed in the paper. Section four presents the central empirical results of the paper. Here we begin with some descriptive statistics. Then 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 instrument. 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, and Upper and Werner (2002) examined German Bund Markets.

The general consensus in the price discovery literature is that the futures markets tend to lead the cash markets, with the main reason advanced being the relatively lower transaction costs in the futures markets. The trading cost hypothesis of price leadership has emerged 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 the 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 spreads exhibit a u-shaped pattern throughout the day with spreads the widest at the opening and closing of trading. In that 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 to future markets as well.

Using an ARMA framework, Grunbichler, Longstaff, and Schwartz (1994) show that, when the underlying is floor traded and the future is electronically screen traded, futures prices lead spot prices by as much as 20 minutes. The findings are consistent with the hypothesis that electronic 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 market (see Stoll and Whaley, 1990, Stephan and Whaley, 1990). Future markets also provide greater immediacy. 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 in the futures market (Grossman and Miller, 1988).

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) makes the assumption of an efficient price common to both the futures and cash market and characterizes a market's contribution to price discovery as its information share defined as the proportion of the efficient price variation that can attributed to that market. Hasbrouck has argued that the appropriate econometric context for the analysis is supplied by the vector error correction model (VECM) (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 VECM 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 markets 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. We complete a similar sort of analysis by comparing daily information shares to relative spreads and trading activity in the two markets.

Another series of papers compare price discovery across stock market index futures and cash markets. Hasbrouck (2003) finds that for, the S&P 500 and Nasdaq-100 indexes, price discovery was dominated by the electronically-traded futures contracts. Kim, Szakmary, and Schwarz (1999) test the transaction costs hypothesis across U.S. stock index futures markets and find that, because of its lower transactions costs, the S&P index futures market dominates price discovery among equity futures markets. Booth, So, and Tse (1999) examine price discovery for the German stock index, index futures, and index options. They find that price discovery was dominated by the spot index and the index futures and that index options contributed relatively little.

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 measuring the reaction to a permanent shock to the efficient price. Permanent and transitory innovations to the prices are identified with a structural model. 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 bonds of different maturities. An innovation in their paper is the study of price discovery in a system of futures and cash bond prices of different maturities. They found that, using just the 10 year bond data, the cash market dominated price discovery from 1995 to 1999. However, in 2000 the cash market information share dropped significantly, because GovPx was no longer representative of the inter-dealer broker market with the advent of new electronic platforms, 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 and 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 electronic trading of the futures contact for this bond is relatively new but still exhibits a high degree of trading and low transactions costs.

3. The CGB and the Ten-Year Government of Canada Bond Market

The source for the spot market data for the Government of Canada 10-year bond is Moneyline Telerate's CanPX system.[1] 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.

During the sample period under study, the IDBs operated as voice brokers with posted quotes representing 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

[1] Further information on the CanPx data can also be found in D'Souza, Gaa and Yang (2003).

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 significant 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.

Only pricing and trading data for the benchmark bond in the cash market is used. The benchmark bond is defined as the most actively traded bond and switches from the old benchmark to a new bond once trading in the newer bond exceeds the old benchmark. In Canada, the ten-year benchmark is built up over time through re-openings of auctions for the same bond. Therefore, unlike the U.S., a bond does not become the new benchmark immediately after its first auction but only after it has reached some critical size and is accepted as the new benchmark by the market.

Data from the Investment Dealers Association show that roughly 55% of the Canadian secondary spot market was customer-dealer trade in 2002, while 45% 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.[2] This is a customer market with no market maker. At any given time there are up to eight contracts available for trading

[2] More details on the CGB market and its characteristics can be found in Campbell and Chung (2003).

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, as in others, 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.[3]

[3] The following fields are included in the dataset: a date and time stamp to the second, ask quantity, ask price, bid price, bid quantity, bid size, trade size, and trade price.

Seven complete contracts fall within the purview of the 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. More precisely, we examine the indicated trading days for each of the seven CGB contracts considered in this study:

Contract	*Trading Days*	
June, 2002	February 26, 2002 – May 29, 2002	[58 trading days]
September, 2002	May 30, 2002– August 28, 2002	[56 trading days]
December, 2002	August 29, 2002 – November 26, 2002	[53 trading days]
March, 2003	November 27, 2002 – February 25, 2003	[56 trading days]
March, 2004	November 27, 2003 – February 25, 2004	[55 trading days]
June, 2004	February 26, 2004 – May 26, 2004	[60 trading days]
September, 2004	May 27, 2004 – August 25, 2004	[57 trading days]

Once days with early pre-holiday closures are excluded, there are 395 complete trading days in the sample. Some days are missing observations at the beginning of the day because of a lack of activity in the cash market. These days are, however, still included in order to maximize the sample of days as long as the time without a cash market price did not last longer than 60 minutes.

3. Price Discovery Across Markets

Both the Hasbrouck and Gonzalo-Granger (GG) 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. Under the Hasbrouck approach, the permanent component is a martingale and accordingly reflects features of efficient market behaviour. By contrast, the non-stationary component in the GG approach is not a martingale and may be forecastable. Our intention 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. Yan and Zivot (2005) also supply a discussion and critique of these techniques.

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

(1) $$\Delta p_t \quad = \quad c + Ap_{t-1} + \sum_j B_j \, \Delta p_{t-j} + v_t \quad .$$

Given the cointegrating vector (1, -1), since the difference between spot and futures prices should be a constant 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) $$p_t \quad = \quad C(1)\sum_{k=1}^{t} v_k + \widetilde{C}(L)v_t + p_0 \quad ,$$

where C(L) gives the MA representation of the price difference process in (1) and $\widetilde{C}(L)$ 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) $$I_j \quad = \quad \frac{c_j^2 \operatorname{var}(v_j)}{cVc'} \quad ; \; j = 1, 2 \; and \; V = \begin{pmatrix} v_1 & 0 \\ 0 & v_2 \end{pmatrix} \; .$$

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 in 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 also considers the variances of the underlying innovations. These points are emphasized in Baillie *et al* (2002).

Note that, by construction, the Hasbrouck information shares are contained in the [0,1] interval. The GG shares in (4), however, are not bounded. To ensure that GG shares are in the [0,1] interval and hence have a more sensible interpretation, we impose the following restrictions on the cointegrating vector loadings or adjustment coefficients: $a_1 \leq 0$ and $a_2 \geq 0$. With the variables ordered in the cointegrating vector as [Pf, -Pc] these restrictions are quite reasonable and should not typically bind.[4]

The above models were also extended to allow for GARCH effects in the variances of each market's price series. Tests using the base model reject the null of homoskedasticity for almost every specification and period investigated. In addition, an examination of simple plots of squared returns shows that there is a seasonal pattern to volatility over the day. This is similar to what is shown in many studies of volatility. There is evidence of increased volatility around 8:30, 10:00, and 14:00. The first two are undoubtedly related to the timing of announcements for major data releases while the afternoon increase is likely a form of end-of-day effect even though it is an hour before close of trading in the futures market. Volatility around 8:30 is much larger than at the other two peaks and even more so above other periods during the day. Due to the computational difficulties of allowing for a seasonal pattern in a GARCH model, only the increased volatility for the 10 minutes following 8:30 will be modeled. To estimate the GARCH model, equation (1) is augmented by assuming the error term follows $v_t \sim N(0,H_t)$ where

$$H_t = C'C + A'v_t v_t' A + B'H_{t-1}B + D'S_t D \quad . \tag{6}$$

This is the BEK specification of Engle and Kroner (1995) which directly imposes positive definiteness on the variance matrix. *A, B, C*, and *D* are parameter matrices and S_t is a seasonal dummy that is 1 for the 10 minutes following 8:30 a.m. and zero otherwise. The GARCH estimation will change the GG information shares only if it affects the error correction coefficients in equation (3).[5] The Hasbrouck shares in equation (4) will be affected both by any change in the error correction coefficients and the new estimate of the variance-covariance matrix H_t. We will use the asymptotic value of H_t to compute the Hasbrouck information shares as opposed to any in-sample average or individual H_t.

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[4] We found that the restrictions were only imposed on 14 of the 395 days and were only rejected for one of those days.

[5] Note that OLS coefficients are unbiased but inefficient in the face of heteroskedasticity, so that the OLS-based GG shares should, in theory, also be unbiased.

We also deal with the issue of higher opening volatility by presenting Gonzalo-Granger and Hasbrouck information shares computed directly for just the first 40 minutes of the trading day. For this specification, only days with a full sample from 8:20 a.m. to 9:00 a.m. were included. This reduced the sample only slightly to 385 from 395 days.

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 converged 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 addition, we will also compute the average time taken to reach a new fundamental price level after a shock. A weighted average across all the possible shocks is computed in the same manner as described above. A price is said to have reached its new fundamental level after a shock when it is within 10% of that new level.

Before proceeding to the empirical results there are two important issues to resolve. The first relates to the choice of the price variable. In this study, we use quotes, more particularly the mid-point of the bid-ask spread, rather than transaction prices as the fundamental variable to be modeled with equation (1). In the Canadian data we are analyzing, there is considerably more price movement throughout the day with this choice and 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 such that it would not seem that prices in one market or the other were not moving. Therefore, there are 800 observations per day from 8:20 a.m. to 3:00 p.m. The VECM model will be estimated daily and the results will report the mean, median, and the 25th and 75th percentiles across the information share estimates for each contract.[6]

4. Price Discovery: Empirical Results

We begin with a discussion of some basic descriptive statistics of activity in the spot and futures markets for 10-year Government debt in Canada before considering the estimation results for the VECM model of price discovery. Here we will consider in turn the statistical significance of the error correction terms, the implications of the Granger causality tests and, finally, the information shares themselves.

Table 1 relates basic trading statistics for the spot and futures markets for the seven contracts in the paper. 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 during the period of the June 2002 contract 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

[6] Estimating over longer periods is, of course, possible but would also require us to model the fact that the futures price will tend to mechanically converge toward the cash market price not because of price discovery but simply due to the futures contract getting closer to maturity.

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.

Trading costs are generally lower on futures markets than on spot markets. Summary statistics on the percentage quoted half spread given in Table 2.[7] Over the sample, the spread has fallen in the CGB market from about 2.42 basis points in the June 2002 Contract to 1.35 basis points in the September 2004 Contract. At the same time, the spot market spread fell from 3.60 to 2.89 basis points. Both markets experienced reduced trading costs over the sample but, in each case, the CGB spreads were smaller by about 30% 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.

The spread data for the intra-day sub-samples reveal that CGB transaction costs increase steadily through the day while the spot market costs could increase or decrease. There was also much less change over the day in the spot market spreads than in the CGB spreads.

It should be noted that the spot market trading statistics are biased down and the spread statistics biased upward by the fact that the markets are compared for the common period of 8:20 am to 3:00 pm. The spot market is actually open from 7:00 am to 5:00 pm and there can be substantial activity during the periods when only the spot market is open. When looking at the statistics for the full spot market day, however, we see that there are more trades and smaller spreads than mentioned above, but that there is still greater activity and lower transaction costs on the CGB market. Further indicators of market liquidity (best and behind-best bid and ask depth, price impact coefficients, etc.) could be computed but were not considered as part of the scope of this paper.[8]

Table 3 summarizes some of the daily estimation results. The table shows, for daily estimation periods, whether the coefficient was significant on the error correction term in the estimation of the futures or cash equations [equation (1)] and the results of a Granger Causality test proposed

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[7] The percentage quoted half spread is 1/2*[(Pask-Pbid)/(Pask+Pbid)/2].

[8] See D'Souza, Gaa, and Yang (2003) for a discussion of various liquidity and order flow measures for the CanPx data.

by Sims that includes lagged dependent variables. In general, both error correction terms were statistically significant implying significant price discovery in each market. On only one day was the error correction term significant in the futures market but not the cash market. There were 118 days with a significant coefficient in the spot equation but not the futures. The remainder had significance in both equations. These results give a strong indication of price discovery in both markets but more predominantly in the futures market because it is the cash market that adjusts most to the disequilibrium measured by the error correction term.

Next, consider the Granger Causality results. There are only 9 days indicating that the cash market causes price movements in the futures market, while there are 226 days implying the reverse with the futures causing the cash. Another 124 days experienced bi-directional causality. Once again this is a strong indication that the futures market dominates price discovery for the 10-year Government of Canada bond.

We now turn to results for the Gonzalo-Granger and Hasbrouck information shares, which are reported in Table 4 for the CGB market. The cash market share is, of course, just one minus the CGB share. Three estimates of the information shares are considered: OLS over the full day, OLS over the first 40 minutes of trading, and a full-day estimate of a GARCH–based specification of the daily volatility patterns as described in the previous section. Information shares reported 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 over the entire day, the share for the futures market has risen from a minimum of 59% in Contract 1 to a high of 73% for Contract 5 according to the Granger-Gonzalo test and has remained close to 70% for all but the first contract. Indeed, the full sample estimate says that 69% of price discovery occurs in the futures market. The Hasbrouck measures track similar results. The Hasbrouck share has risen from a 63%-72% range in the first contract up to a range of 76%-86% for Contract 5 before falling back slightly. In general, the Hasbrouck information share tends to yield a fairly tight range around a midpoint that is slightly larger than the results for the Granger-Gonzalo share. The plots in Figure 1 give a flavour of the day-by-day movements on these shares for three of the seven contracts: Contracts 1, 4, and 5.[9] We see the tight range for the Hasbrouck numbers throughout each contract and that the OLS results tend to fall slightly below that range. Some of the contracts, particularly contracts 1, 5, and 7, appear to have lower futures market information shares at the beginning of the contract but it is difficult to identify a similar pattern in the other contracts. What is visually notable is the high daily volatility across each contract. This feature is also evident in the results for the 25th percentile, 75th percentile, and standard deviation reported in Table 4.

This variability of the information estimates across the contract is also reflected in the results for the two other estimation procedures. In one, we restricted the OLS estimation to the first 40 minutes of trading from 8:20a.m to 9:00a.m. With this sample, the futures market information share was slightly lower at 62% for the GG technique and 61%-74% for the Hasbrouck share. However, the variability of these estimates across the seven contracts is much more pronounced, up to 60% larger than the full day estimates for some contracts. Figure 2 gives the daily plots for the three representative contracts. It is also evident here that this restricted estimation procedure leads to more variable estimates of information shares across each contract.

By contrast, the GARCH estimates show significantly smaller information shares being attributed to the futures market for some contracts. Over the full sample, there is about a 10 percentage point drop in the estimated GG information share. The Hasbrouck midpoint drops by a similar amount with the range shifting downwards and considerably widening. Correcting in this way for the presence of heteroskedasticity in the data and the intra-day variance pattern shows that the basic results may over-attribute price discovery to the futures market. However, the GARCH results are themselves quite variable occupying the middle ground in this regard between the full-day OLS estimates and the morning OLS estimates for the Gonzalo-Granger measure [see Figure 2] and the most variable for the Hasbrouck measure.

To pursue this issue further we plot in Figure 3 the 95% bootstrap confidence bands of the OLS estimates and the GARCH estimates of the GG share. The confidence bands in these figures are

[9] The results for these three contracts are representative of the characteristics of all seven. The plots for the other contracts are excluded in the interest of saving space and are available on request.

the 5th and 95th percentiles from 1000 bootstrap samples of the OLS specification for each day. The results imply a 90% confidence band of about +/- 0.15 (or from about 0.53 to 0.83) around each daily estimate. Returning to Figure 3, we see, that while more volatile, the GARCH estimates tend to fall within the OLS confidence bands.

Bootstrap results presented in Table 5 confirm the basic conclusion of this section that well over half of price discovery occurs on the futures market.[10] Here we see that, over the full sample, the GG measure for the futures market is greater than 0.5 for almost 90% of the days while for 61% of days the bootstrap confidence interval for the information share is greater than 0.5. Similar results obtain for the mid-point of the Hasbrouck measures: for 86% of the days the share is greater than 0.5 while for 50% of the days the confidence interval for the mid-point surpasses 0.5. Also note that there was a jump from 38% for Contract 1 to 61% for Contract 2 in the percentage of days with a GG estimate significantly greater than 0.5 (from 26% to 46% for the Hasbrouck lower bound over the same period).

The next two tables present results in the spirit of Yan and Zivot (2004). Table 6 presents the cumulative difference between the impulse response in each period and the long-run value to which the price converged following the shock. Figure 4 plots the average of impulse responses across all of the days for both a futures and a cash market price shock. The cumulative deviation from the long-run value is computed for the first 1000 periods after the shock. From this example day's results, we see that the cash market tends to deviate more and for longer than the futures market. For the OLS-day and GARCH estimates, the cumulative absolute deviation of the spot market from its equilibrium value is approximately two to three times (except for the first contract) larger than that experienced by the futures market. This result is a strong indication that the cash market exhibits a substantially slower rate of convergence and price discovery than does the futures market. The difference is not as pronounced for the OLS-morning estimates. The bootstrap results in the table's right panel confirm this conclusion concerning the superior efficiency of the futures market: over the entire sample, for 45% of the trading days (172 of 395

[10] Only bootstrap results for the OLS estimates were generated. Bootstrap bands for the GARCH estimates were computationally infeasible to compute.

days), the cumulative difference is statistically higher for the cash market, while in only 3% of the days (11 of 395 days) is it statistically lower.

From Table 7 we are able to draw the same conclusion from a somewhat different perspective in analyzing the impulse response functions for the two markets. Here we focus on the number of minutes it takes for the market to converge to its long-run equilibrium.[11] For example, the difference in convergence times between markets is about 4 minutes in favour of the futures market. This speedier pattern is seen in each of the contracts, ranging from three minutes in the first contract to six minutes in the fourth. As in the previous table, there does not appear to be a difference between the OLS-day results and the GARCH results in favouring the futures market. The difference between the futures and cash markets is not as pronounced for the estimates restricted to the opening trading period. Interestingly though, the mean times for convergence following a shock are lower for the opening period than for either of the other estimates. This is somewhat surprising given this is the period during which the most important macro news announcements are released and hence is likely to have the greatest degree of uncertainty. The bootstrap confidence intervals underscore the point: in almost 50% of the days over the whole sample, the speed of convergence of the futures market is statistically superior to that of the cash market.

5. Determinants of the Information Shares

In this section, we regress information shares on various measures of trading costs and activity in an attempt to explain the daily variation. The average daily percentage bid-ask half spread is included to measure trading costs or liquidity. Wider spreads in the futures market should decrease that market's information share while higher spreads in the spot market should increase it. Trading activity is measured by total daily number of trades. More trading in the futures market should raise its information share while greater trading in the spot market should decrease it. Liquidity and trading activity are included either for each market individually or as a ratio of the two markets. Also included in the regressions is a dummy variable equal to one if the day is

[11] See Figure 4 for an example showing how the time until convergence was computed. The figure plots the average across all of the days for one ordering of the OLS-full day impulse responses. In the top panel, for a futures price shock, the futures market takes about four minutes while the cash market took about eight minutes to come within 10% of the long-run value.

one of the first three of a contract and zero otherwise. This variable is to test the observation that information shares seem to be lower at the start of a contract. Finally, we include a dummy equal to one for Contracts 2 through 7 and zero for Contract 1 in order to test whether there was a significant increase in the futures market information share at that time. Table 8 gives the results for the daily GG and the midpoint of the Hasbrouck range for each of the three specifications: full-day OLS, opening OLS, and GARCH.

The results show that the equation fits best for the full-day OLS estimates but quite poorly for the opening-period OLS sample. The fit for the GARCH estimates was in between the others. The pattern of signs and significance was the same for the full-day OLS and GARCH estimates and for both the GG and Hasbrouck midpoint information shares. We see that the first three days of a new contract have significantly lower futures market information share, that there was a significant increase in the share after Contract 1, that the spread variables are sensible with the own market spread reducing the futures information share but the cash market spread increasing the futures market information share, and that the number of trades in the cash market has a positive instead of the expected negative effect. When the spread and trade variables are expressed as a ratio of the two markets to account for collinearity, relatively higher spreads or trading costs in the futures market still decreases that market's information share while relatively more trading in the futures market still has the anomalous result of also decreasing price discovery in the futures market. Evidently, the ratio of the number of trades in the two markets does not adequately capture the concept of relative depth or liquidity.

In sum, daily information shares respond as expected to trading costs in the two markets. Higher spreads or trading costs in the futures (cash) market will lower (increase) the share of price discovery that occurs in that market. The effect of relative trading activity is significant but contrary to expectations.

6. Conclusions and Future Research

After considerable analysis 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 matured since the first contract studied. This outcome is certainly consistent with priors that price discovery occurs on the market with the lower transaction costs.

This conclusion concerning the relative efficiency of the futures can be extended along several dimensions. The CanPX data used in this study only covers a portion of trading in the secondary cash market. Future work will incorporate pricing information from the dealer-customer sector of the secondary market, so that the price discovery process can be simultaneously investigated across the futures market, the inter-dealer cash market, and the dealer-customer cash market. The focus of this study has been on quote prices. We intend in future work to look at transaction prices, as well as to incorporate quantity effects such as quote volumes and trade flows in the analysis in keeping with recent microstructure research in other markets. A third initiative involves a comparison with US data in which we ask whether the Canadian price discovery process resembles that of the US .

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Table 1: CGB and Ten-Year Bond Trading Statistics

February 26, 2002 - February 25, 2003
November 27, 2003 - August 25, 2004

Contract Maturity	Daily Volume Traded		Daily Number of Trades		Daily Trade Size	
	CGB	Spot	CGB	Spot	CGB	Spot
Contract 1: June 2002	5251	166	542	35	9.8	4.7
Contract 2: September 2002	4936	166	543	34	9.1	4.8
Contract 3: December 2002	5514	163	617	39	9	4.3
Contract 4: March 2003	5916	151	809	33	7.3	4.4
Contract 5: March 2004	6054	174	742	43	8.1	4.1
Contract 6: June 2004	8424	193	894	43	9	4.6
Contract 7: September 2004	7371	160	954	37	7.8	4.3

Trade size and volume is in millions of dollars in the bond market and is the number of contracts in the CGB market where each contract has a notional value of $100,000. The numbers in the Table are averages of daily averages.

Table 2: Percentage Quoted Half Spread

February 26, 2002 - February 25, 2003
November 27, 2003 - August 25, 2004

Contract Maturity	8:20am - 10:59am		11:00am - 1:59pm		2:00pm - 3:00pm		All Day	
	CGB	Spot	CGB	Spot	CGB	Spot	CGB	Spot
Contract 1: June 2002	2.09	3.64	2.63	3.58	2.69	3.52	2.42	3.60
	(0.55)	(0.89)	(0.78)	(0.84)	(1.26)	(1.19)	(0.60)	(0.69)
Contract 2: September 2002	2.02	3.58	2.71	3.90	2.76	3.83	2.44	3.76
	(0.54)	(0.69)	(0.74)	(0.99)	(1.07)	(1.40)	(0.54)	(0.66)
Contract 3: December 2002	1.94	3.63	2.51	3.82	2.75	3.68	2.32	3.72
	(0.46)	(0.97)	(0.55)	(0.96)	(1.43)	(1.48)	(0.44)	(0.71)
Contract 4: March 2003	1.45	3.25	1.48	3.21	1.69	3.27	1.50	3.25
	(0.53)	(0.76)	(0.56)	(0.76)	(0.85)	(1.45)	(0.53)	(0.69)
Contract 5: March 2004	1.45	3.18	1.90	3.22	2.12	3.26	1.75	3.20
	(0.35)	(0.62)	(0.54)	(0.67)	(1.06)	(1.20)	(0.43)	(0.45)
Contract 6: June 2004	1.25	2.88	1.56	2.69	1.80	2.71	1.47	2.77
	(0.29)	(0.62)	(0.41)	(0.56)	(0.64)	(1.03)	(0.29)	(0.45)
Contract 7: September 2004	1.10	2.96	1.47	2.81	1.68	2.81	1.35	2.89
	(0.29)	(1.12)	(0.37)	(0.71)	(0.92)	(1.13)	(0.34)	(0.74)
Full Sample	1.60	3.30	2.02	3.31	2.20	3.29	1.88	3.30
	(0.57)	(0.87)	(0.78)	(0.90)	(1.15)	(1.33)	(0.64)	(0.73)

Spreads are in basis points. Standard errors are in parentheses.

Table 3: Granger Causality and Error Correction

February 26, 2002 - February 25, 2003

November 27, 2003 - August 25, 2004

Contract Maturity	Number of Trading Days	Granger Causality			VECM	
		F □ C	C □ F	F □ C	ecm F	ecm C
Contract 1: June 2002	58	24	4	24	50 [1]	57 [8]
Contract 2: September 2002	56	35	1	12	41 [1]	56 [15]
Contract 3: December 2002	53	34	2	12	32 [0]	53 [21]
Contract 4: March 2003	56	37	1	12	31 [0]	56 [25]
Contract 5: March 2004	55	30	1	19	40 [0]	55 [15]
Contract 6: June 2004	60	33	0	21	43 [0]	60 [17]
Contract 7: September 2004	57	31	0	23	40 [0]	57 [17]
Totals	395	224	9	123	277 [1]	394 [118]

The numbers in each cell represent the number of trading days for the contract in question. The arrows indicate the direction of Granger causality using the charaterizaton due to Sims. The results reported under VECM indicate significance of the relevant t-test at the 5% level in equation (1). Numbers in [ ] indicate the number of days the coefficient was significant in the market indicated but not in the other.

Table 4: Price Discovery Information Shares for the CGB Futures Market

Contract Maturity		Information Share Gonzalo-Granger					Information Share Hasbrouck LB					Information Share Hasbrouck UB			
		Mean	Median	$Q_{(.25)}$	$Q_{(.75)}$	Std.Dev.	Mean	Median	$Q_{(.25)}$	$Q_{(.75)}$	Std.Dev.	Mean	Median	$Q_{(.25)}$	$Q_{(.75)}$
C1: June 2002	**OLS-day**	0.59	0.58	0.50	0.70	0.163	0.63	0.68	0.51	0.78	0.210	0.72	0.77	0.62	0.85
	OLS-opening	0.60	0.62	0.43	0.80	0.264	0.60	0.62	0.37	0.88	0.303	0.72	0.80	0.53	0.95
	GARCH	0.52***	0.53	0.40	0.65	0.196	0.39***	0.26	0.09	0.67	0.344	0.84***	0.95	0.85	0.99
C2: September 2002	**OLS-day**	0.69	0.68	0.59	0.78	0.152	0.73	0.74	0.60	0.86	0.168	0.83	0.84	0.76	0.92
	OLS-opening	0.67	0.67	0.48	0.90	0.240	0.66**	0.72	0.41	0.93	0.281	0.78**	0.86	0.64	0.99
	GARCH	0.63***	0.62	0.51	0.74	0.179	0.43***	0.37	0.17	0.67	0.239	0.86	0.97	0.84	1.00
C3: December 2002	**OLS-day**	0.72	0.74	0.62	0.83	0.169	0.76	0.81	0.63	0.90	0.189	0.85	0.90	0.80	0.96
	OLS-opening	0.60***	0.59	0.39	0.83	0.262	0.62***	0.66	0.40	0.89	0.300	0.75***	0.82	0.61	0.98
	GARCH	0.61***	0.61	0.44	0.77	0.218	0.44***	0.45	0.11	0.71	0.275	0.86	0.99	0.90	1.00
C4: March 2003	**OLS-day**	0.72	0.70	0.61	0.83	0.145	0.75	0.77	0.67	0.88	0.166	0.85	0.85	0.75	0.97
	OLS-opening	0.56***	0.61	0.31	0.83	0.313	0.56***	0.63	0.25	0.84	0.322	0.70***	0.81	0.41	0.97
	GARCH	0.62***	0.60	0.48	0.72	0.175	0.55***	0.60	0.26	0.79	0.237	0.92***	0.99	0.93	1.00
C5: March 2004	**OLS-day**	0.73	0.74	0.64	0.80	0.139	0.76	0.78	0.69	0.85	0.140	0.86	0.88	0.82	0.94
	OLS-opening	0.64***	0.59	0.37	0.99	0.307	0.63***	0.67	0.37	0.95	0.325	0.75***	0.84	0.57	1.00
	GARCH	0.61***	0.62	0.49	0.73	0.213	0.48***	0.51	0.21	0.74	0.260	0.91**	0.98	0.90	1.00
C6: June 2004	**OLS-day**	0.70	0.70	0.61	0.78	0.148	0.73	0.75	0.66	0.86	0.173	0.84	0.88	0.80	0.94
	OLS-opening	0.69	0.74	0.47	0.96	0.280	0.67*	0.76	0.42	0.96	0.303	0.79**	0.90	0.66	1.00
	GARCH	0.60***	0.62	0.46	0.73	0.208	0.47***	0.45	0.13	0.84	0.252	0.89**	0.98	0.92	1.00
C7: September 2004	**OLS-day**	0.67	0.68	0.55	0.79	0.197	0.68	0.74	0.53	0.84	0.213	0.80	0.84	0.72	0.93
	OLS-opening	0.57***	0.61	0.39	0.80	0.281	0.54***	0.58	0.24	0.87	0.333	0.71**	0.84	0.49	0.95
	GARCH	0.57***	0.58	0.47	0.68	0.197	0.46***	0.44	0.09	0.83	0.247	0.87**	0.99	0.88	1.00
Full Sample	**OLS-day**	0.69	0.69	0.58	0.80	0.165	0.72	0.74	0.61	0.86	0.186	0.82	0.85	0.75	0.94
	OLS-opening	0.62***	0.63	0.41	0.84	0.281	0.61***	0.66	0.35	0.90	0.311	0.74***	0.84	0.59	0.98
	GARCH	0.59***	0.60	0.46	0.72	0.200	0.46***	0.45	0.13	0.75	0.254	0.88***	0.98	0.89	1.00

The numbers are averages of daily estimates over the contract. The Gonzalo-Granger numbers come from the estimation of equation (4). The Hasbrouck bounds are described in the text.The first row of each contract is estimated using OLS on the full day while the second row is estimated using OLS on only data from 8:20am to 9:00am. The third row of results are derived from a GARCH BEKK specification with a dummy to capture an 8:30-8:40 intra-day seasonal effect. See the text for further details.

***, **, * denote significantly different from OLS-day results at 1%, 5%, and 10% levels, respectively, using a pairwise t-test of means.

Table 5: Price Discovery Information Share Confidence Bands

Contract Maturity		Information Share Gonzalo-Granger					Information Share Hasbrouck LB			Information Share Hasbrouck UB				
		5%	Mean	95%	%Days>0.5	%Days<0.5	5%	Mean	95%	5%	Mean	95%	%Days>0.5	%Days<0.5
C1: June 2002	**OLS-day**	0.57	0.59	0.61	0.36	0.07	0.58	0.63	0.64	0.68	0.72	0.73	0.26	0.03
	OLS-opening	0.53	0.60	0.62	0.17	0.05	0.51	0.60	0.61	0.64	0.72	0.74	0.09	0.02
	GARCH	n.a.	0.52	n.a.	n.a.	n.a.	n.a.	0.39	n.a.	n.a.	0.84	n.a.	n.a.	n.a.
C2: September 2002	**OLS-day**	0.67	0.69	0.71	0.61	0.00	0.69	0.73	0.74	0.79	0.83	0.83	0.48	0.00
	OLS-opening	0.59	0.67	0.68	0.31	0.02	0.57	0.66	0.67	0.70	0.78	0.79	0.15	0.00
	GARCH	n.a.	0.63	n.a.	n.a.	n.a.	n.a.	0.43	n.a.	n.a.	0.86	n.a.	n.a.	n.a.
C3: December 2002	**OLS-day**	0.69	0.72	0.73	0.72	0.04	0.71	0.76	0.77	0.81	0.85	0.86	0.68	0.00
	OLS-opening	0.54	0.60	0.62	0.21	0.06	0.53	0.62	0.63	0.67	0.75	0.76	0.09	0.02
	GARCH	n.a.	0.61	n.a.	n.a.	n.a.	n.a.	0.44	n.a.	n.a.	0.86	n.a.	n.a.	n.a.
C4: March 2003	**OLS-day**	0.69	0.72	0.73	0.61	0.00	0.70	0.75	0.76	0.80	0.85	0.85	0.45	0.00
	OLS-opening	0.49	0.56	0.58	0.20	0.15	0.47	0.56	0.57	0.62	0.70	0.72	0.07	0.02
	GARCH	n.a.	0.62	n.a.	n.a.	n.a.	n.a.	0.55	n.a.	n.a.	0.92	n.a.	n.a.	n.a.
C5: March 2004	**OLS-day**	0.71	0.73	0.74	0.75	0.02	0.72	0.76	0.77	0.83	0.86	0.87	0.65	0.00
	OLS-opening	0.56	0.64	0.64	0.31	0.06	0.54	0.63	0.64	0.67	0.75	0.77	0.22	0.00
	GARCH	n.a.	0.61	n.a.	n.a.	n.a.	n.a.	0.48	n.a.	n.a.	0.91	n.a.	n.a.	n.a.
C6: June 2004	**OLS-day**	0.68	0.70	0.72	0.67	0.00	0.69	0.73	0.74	0.80	0.84	0.85	0.48	0.00
	OLS-opening	0.60	0.69	0.68	0.31	0.05	0.58	0.67	0.67	0.72	0.79	0.80	0.19	0.00
	GARCH	n.a.	0.60	n.a.	n.a.	n.a.	n.a.	0.47	n.a.	n.a.	0.89	n.a.	n.a.	n.a.
C7: September 2004	**OLS-day**	0.64	0.67	0.68	0.58	0.07	0.64	0.68	0.69	0.76	0.80	0.81	0.44	0.04
	OLS-opening	0.51	0.57	0.60	0.13	0.13	0.47	0.54	0.57	0.64	0.71	0.74	0.07	0.00
	GARCH	n.a.	0.57	n.a.	n.a.	n.a.	n.a.	0.46	n.a.	n.a.	0.87	n.a.	n.a.	n.a.
Full Sample	**OLS-day**	0.67	0.69	0.69	0.61	0.03	0.69	0.72	0.71	0.80	0.82	0.81	0.49	0.01
	OLS-opening	0.57	0.62	0.60	0.23	0.07	0.55	0.61	0.59	0.70	0.74	0.73	0.13	0.01
	GARCH	n.a.	0.59	n.a.	n.a.	n.a.	n.a.	0.46	n.a.	n.a.	0.88	n.a.	n.a.	n.a.

The numbers are averages of daily estimates over the contract. The Gonzalo-Granger numbers come from the estimation of equation (4). The Hasbrouck bounds are described in the text.The first row of each contract is estimated using OLS on the full day while the second row is estimated using OLS on only data from 8:20am to 9:00am. The third row of results are derived from a GARCH BEKK specification with a dummy to capture an 8:30-8:40 intra-day seasonal effect. See the text for further details.

% Days>0.5 is the percent of days within the contract period for which the GG or Hasbrouck lower bound information share was significantly greater than 0.5 at the 5% significance level.

% Days<0.5 is the percent of days for which the GG or Hasbrouck upper bound was significantly less than 0.5.

Table 6: Sum of Impulse Response Deviations

Contract Maturity		Futures Market			Spot Market			Comparison			
								% of Days of significant difference			
		5%	Mean	95%	5%	Mean	95%	Spot>Futures	Futures> Spot	No Difference	# of Days
C1: June 2002	OLS-day	0.037	0.041	0.044	0.056	0.063***	0.066	0.24	0.07	0.69	58
	OLS-opening	0.024	0.030	0.039	0.029	0.043**	0.048	0.24	0.07	0.69	58
	GARCH	n.a.	0.042	n.a.	n.a.	0.065***	n.a.	n.a.	n.a.	n.a.	n.a.
C2: September 2002	OLS-day	0.025	0.026	0.030	0.064	0.075***	0.076	0.41	0.00	0.57	56
	OLS-opening	0.022	0.029	0.039	0.031	0.051***	0.053	0.38	0.00	0.58	52
	GARCH	n.a.	0.029	n.a.	n.a.	0.080***	n.a.	n.a.	n.a.	n.a.	n.a.
C3: December 2002	OLS-day	0.022	0.024	0.027	0.058	0.066***	0.068	0.51	0.00	0.47	53
	OLS-opening	0.022	0.028	0.034	0.028	0.038**	0.043	0.51	0.00	0.47	53
	GARCH	n.a.	0.025	n.a.	n.a.	0.068***	n.a.	n.a.	n.a.	n.a.	n.a.
C4: March 2003	OLS-day	0.021	0.022	0.026	0.054	0.065***	0.068	0.32	0.02	0.64	56
	OLS-opening	0.022	0.028	0.034	0.023	0.035	0.042	0.32	0.02	0.64	55
	GARCH	n.a.	0.022	n.a.	n.a.	0.064***	n.a.	n.a.	n.a.	n.a.	n.a.
C5: March 2004	OLS-day	0.017	0.018	0.021	0.046	0.050***	0.052	0.53	0.00	0.45	55
	OLS-opening	0.019	0.022	0.028	0.026	0.037***	0.040	0.53	0.00	0.44	54
	GARCH	n.a.	0.019	n.a.	n.a.	0.053***	n.a.	n.a.	n.a.	n.a.	n.a.
C6: June 2004	OLS-day	0.020	0.022	0.025	0.046	0.051***	0.053	0.39	0.00	0.60	60
	OLS-opening	0.022	0.026	0.035	0.035	0.049***	0.052	0.39	0.00	0.59	58
	GARCH	n.a.	0.025	n.a.	n.a.	0.056***	n.a.	n.a.	n.a.	n.a.	n.a.
C7: September 2004	OLS-day	0.023	0.026	0.029	0.043	0.050***	0.052	0.33	0.05	0.60	57
	OLS-opening	0.024	0.030	0.118	0.027	0.036	0.090	0.32	0.05	0.60	55
	GARCH	n.a.	0.029	n.a.	n.a.	0.053***	n.a.	n.a.	n.a.	n.a.	n.a.
Full Sample	OLS-day	0.025	0.026	0.027	0.055	0.060***	0.059	0.39	0.02	0.58	395
	OLS-opening	0.025	0.028	0.047	0.032	0.041***	0.050	0.38	0.02	0.57	385
	GARCH	n.a.	0.027	n.a.	n.a.	0.063***	n.a.	n.a.	n.a.	n.a.	n.a.

The numbers are averages of daily estimates over the contract. They represent the cumulative sum of the absolute deviation of the impulse response from its long run value. 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 value.

***, **, * denotes spot and futures results significantly different at 1%, 5%, and 10% levels, respectively, using a pairwise t-test of means.

The column Spot>Futures represents the percent of days for which the spot market result was significantly greater than the futures market at the 90% significance level.

Table 7: Number of Minutes until Long-Run Equilibrium is Attained

Contract Maturity		Futures Market			Spot Market			Difference			Comparison			
											% of Days of significant difference			
		5%	Mean	95%	5%	Mean	95%	5%	Mean	95%	Spot>Futures	Futures>Spot	No Difference	# of Days
C1: June 2002	OLS-day	7.72	8.86	9.11	10.35	11.75	11.65	1.66	2.88***	3.53	0.28	0.07	0.66	58
	OLS-morning	3.33	4.50	4.93	3.48	5.28	5.18	-0.76	0.78	1.11	0.28	0.07	0.66	58
	GARCH	n.a.	8.84	n.a.	n.a.	11.76	n.a.	n.a.	2.92***	n.a.	n.a.	n.a.	n.a.	n.a.
C2: September 2002	OLS-day	5.00	5.65	6.18	9.26	10.43	10.45	3.43	4.78***	5.12	0.50	0.00	0.50	56
	OLS-morning	3.04	3.82	4.31	3.55	4.98	4.70	-0.33	1.17**	1.25	0.50	0.00	0.50	52
	GARCH	n.a.	5.65	n.a.	n.a.	10.39	n.a.	n.a.	4.74***	n.a.	n.a.	n.a.	n.a.	n.a.
C3: December 2002	OLS-day	4.34	4.96	5.42	8.81	9.82	9.88	3.71	4.86***	5.25	0.66	0.04	0.30	53
	OLS-morning	3.05	4.34	4.43	3.46	4.60	4.76	-0.44	0.26	1.21	0.66	0.04	0.30	53
	GARCH	n.a.	4.97	n.a.	n.a.	9.75	n.a.	n.a.	4.78***	n.a.	n.a.	n.a.	n.a.	n.a.
C4: March 2003	OLS-day	5.29	5.95	7.41	10.92	12.97	13.15	4.20	7.02***	7.34	0.43	0.02	0.55	56
	OLS-morning	3.61	4.82	5.88	3.41	5.07	5.20	-1.57	0.24	0.82	0.44	0.02	0.55	55
	GARCH	n.a.	5.87	n.a.	n.a.	11.87	n.a.	n.a.	6.00***	n.a.	n.a.	n.a.	n.a.	n.a.
C5: March 2004	OLS-day	3.90	4.49	4.83	7.38	8.15	8.19	2.83	3.66***	4.01	0.60	0.02	0.38	55
	OLS-morning	2.81	3.57	3.90	3.13	4.50	4.32	-0.32	0.94**	1.06	0.61	0.02	0.37	54
	GARCH	n.a.	4.43	n.a.	n.a.	8.12	n.a.	n.a.	3.69***	n.a.	n.a.	n.a.	n.a.	n.a.
C6: June 2004	OLS-day	5.06	5.91	6.30	8.59	9.75	9.84	2.74	3.84***	4.32	0.50	0.00	0.50	60
	OLS-morning	2.71	3.41	3.84	3.40	4.96	4.60	-0.01	1.56***	1.48	0.52	0.00	0.48	58
	GARCH	n.a.	5.80	n.a.	n.a.	9.69	n.a.	n.a.	3.90***	n.a.	n.a.	n.a.	n.a.	n.a.
C7: September 2004	OLS-day	5.22	5.93	6.43	8.83	10.05	10.04	2.76	4.12***	4.46	0.42	0.05	0.53	57
	OLS-morning	2.83	3.08	8.70	3.45	4.59	8.90	-1.11	1.51**	2.76	0.42	0.05	0.53	55
	GARCH	n.a.	5.85	n.a.	n.a.	9.93	n.a.	n.a.	4.08***	n.a.	n.a.	n.a.	n.a.	n.a.
Full Sample	OLS-day	5.62	5.99	6.14	9.54	10.43	10.06	3.56	4.44***	4.29	0.48	0.03	0.49	395
	OLS-morning	3.41	3.93	4.56	3.78	4.86	4.81	-0.10	0.93***	0.84	0.49	0.03	0.49	385
	GARCH	n.a.	5.94	n.a.	n.a.	10.23	n.a.	n.a.	4.29***	n.a.	n.a.	n.a.	n.a.	n.a.

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 impulse 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 value.

***, **, * denotes spot and futures results significantly different at 1%, 5%, and 10% levels, respectively, using a pairwise t-test of means.

The column Spot>Futures represents the percent of days for which the spot market result was significantly greater than the futures market at the 90% significance level.

Table 8: Regression Results using Futures Market Daily Information Shares

	Gonzalo-Granger						Hasbrouck - Mid-Point					
	OLS-day	OLS-day	OLS-open	OLS-open	GARCH	GARCH	OLS-day	OLS-day	OLS-open	OLS-open	GARCH	GARCH
Constant	0.401	1.121	0.386	0.725	0.293	0.796	0.543	1.052	0.453	0.695	0.671	1.100
	(7.502)***	(11.098)***	(3.726)***	(3.656)***	(4.232)***	(6.087)***	(9.614)***	(9.962)***	(4.265)***	(3.416)***	(8.000)***	(7.015)***
FIRST3DAYS	-0.159	-0.181	-0.136	-0.151	-0.064	-0.087	-0.169	-0.182	-0.120	-0.131	-0.107	-0.115
	(-3.910)***	(-4.357)***	(-1.748)*	(-1.953)*	(-1.207)	(-1.613)	(-3.928)***	(-4.205)***	(-1.507)	(-1.644)	(-1.708)*	(-1.840)*
CONTRACT #2-#7	0.091	0.098	0.036	0.035	0.081	0.084	0.101	0.099	0.041	0.029	0.038	0.050
	(4.096)***	(4.439)***	(0.837)	(0.858)	(2.810)***	(2.971)***	(4.303)***	(4.310)***	(0.938)	(0.680)	(1.110)	(1.477)
MEAN HALF SPREAD-F	-0.048		0.012		-0.028		-0.041		0.011		-0.057	
	(-4.175)***		(0.534)		(-1.881)*		(-3.433)***		(0.480)		(-3.007)***	
MEAN HALF SPREAD-C	0.056		0.021		0.050		0.049		0.028		0.025	
	(5.706)***		(1.071)		(3.928)***		(4.694)***		(1.438)		(1.482)	
NUMBER OF TRADES-F	0.006		0.006		0.001		-0.003		-0.004		-0.030	
	(0.645)		(0.339)		(0.111)		(-0.318)		(-0.182)		(-1.928)*	
NUMBER OF TRADES-C	0.038		0.026		0.037		0.025		0.017		0.042	
	(4.224)***		(1.470)		(3.114)***		(2.560)***		(0.946)		(3.005)***	
RATIO SPREAD		-0.910		-0.076		-0.431		-0.678		0.046		-0.746
		(-5.610)***		(-0.240)		(-2.054)**		(-4.003)***		(0.144)		(-2.935)***
RATIO TRADES		-0.299		-0.208		-0.202		-0.181		-0.113		-0.344
		(-3.588)***		(-1.254)		(-1.877)*		(-2.083)**		(-0.666)		(-2.692)***
RSQ	0.205	0.171	0.009	0.005	0.071	0.035	0.149	0.134	0.006	-0.001	0.038	0.034
NOBS	395	395	385	385	395	395	395	395	385	385	395	395

FIRST3DAYS is one for each of the first three days of a contract and zero otherwise. CONTRACT#2-#7 is one for Contract #2 to #7 and zero for Contract #1.
MEAN HALF SPREAD-F(C) is the percentage quote half spread in the futures (cash) market. NUMBER OF TRADES-F (C) is the number of trades in the futures (cash) market.
RATIO SPREAD is the ratio of the percentage half spread in the futures market to the spread in the cash market. RATIO TRADES is the ratio of the number of trades in the futures and cash markets.
***, **, * spot and futures results significantly different at 1%, 5%, and 10% levels, respectively, using a pairwise t-test of means.

Figure 1
CGB Price Discovery Shares By Contract-OLS Full Day

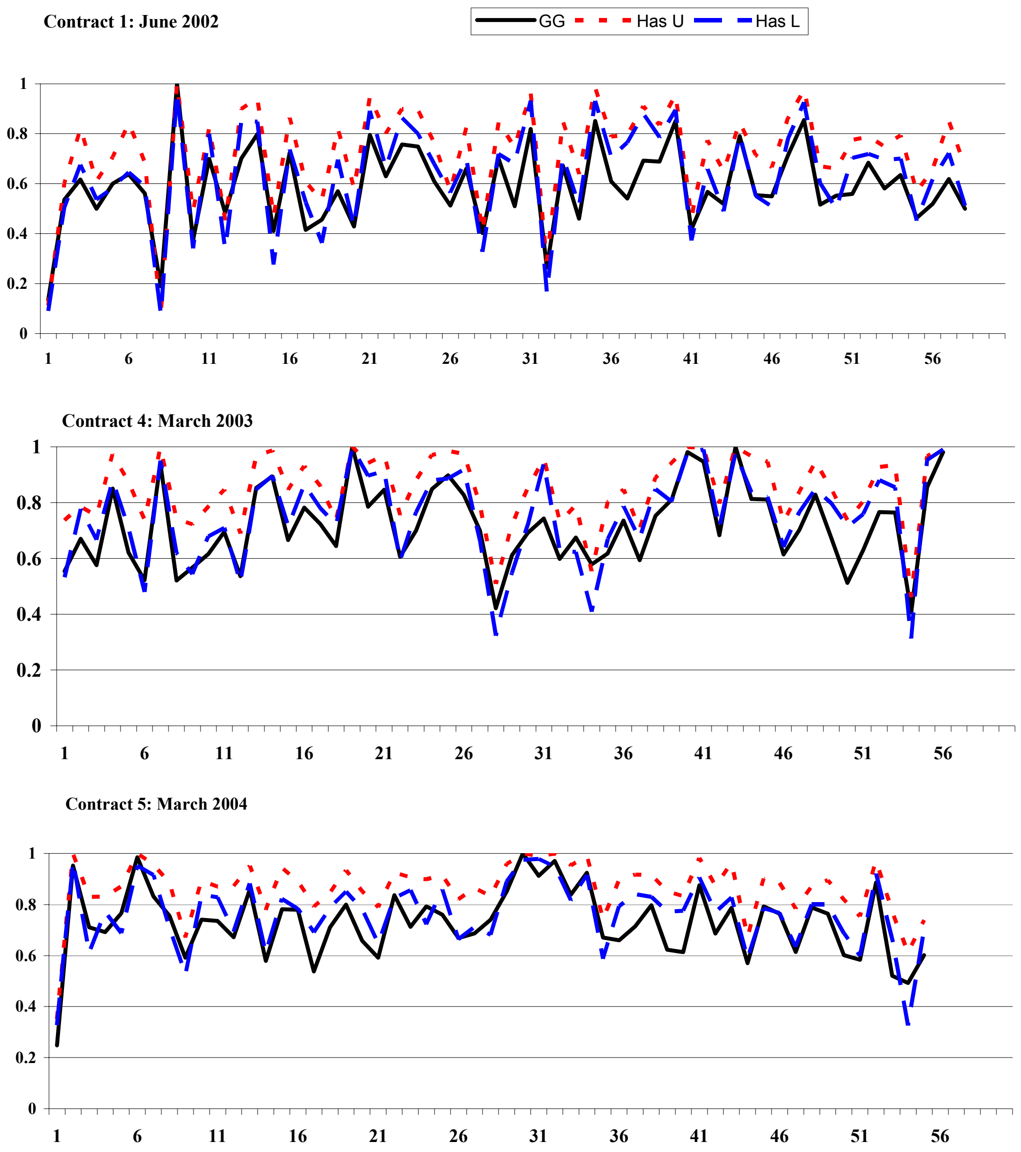

Figure 2
CGB Price Discovery Shares By Contract - GG Measure

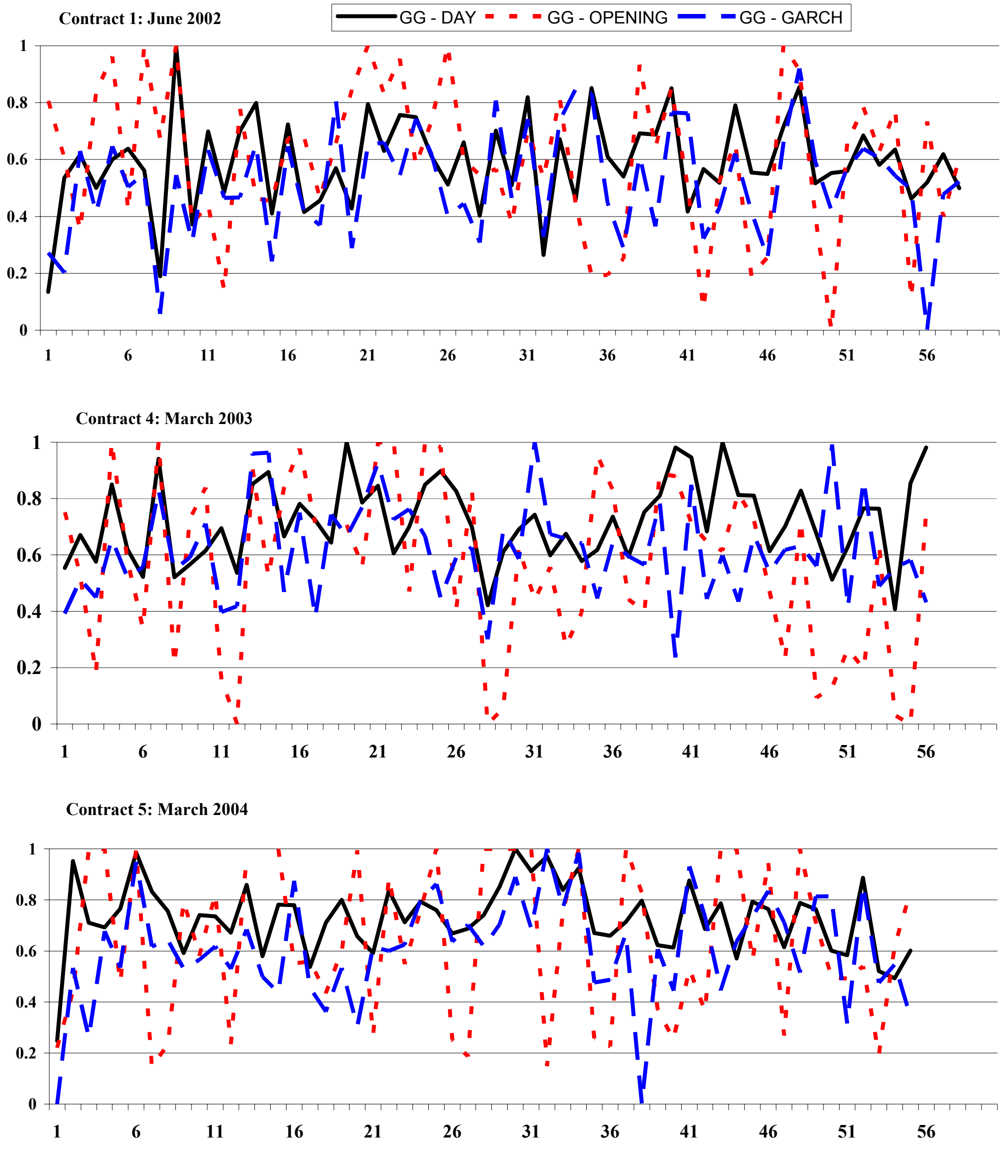

Figure 3
CGB Price Discovery Shares By Contract

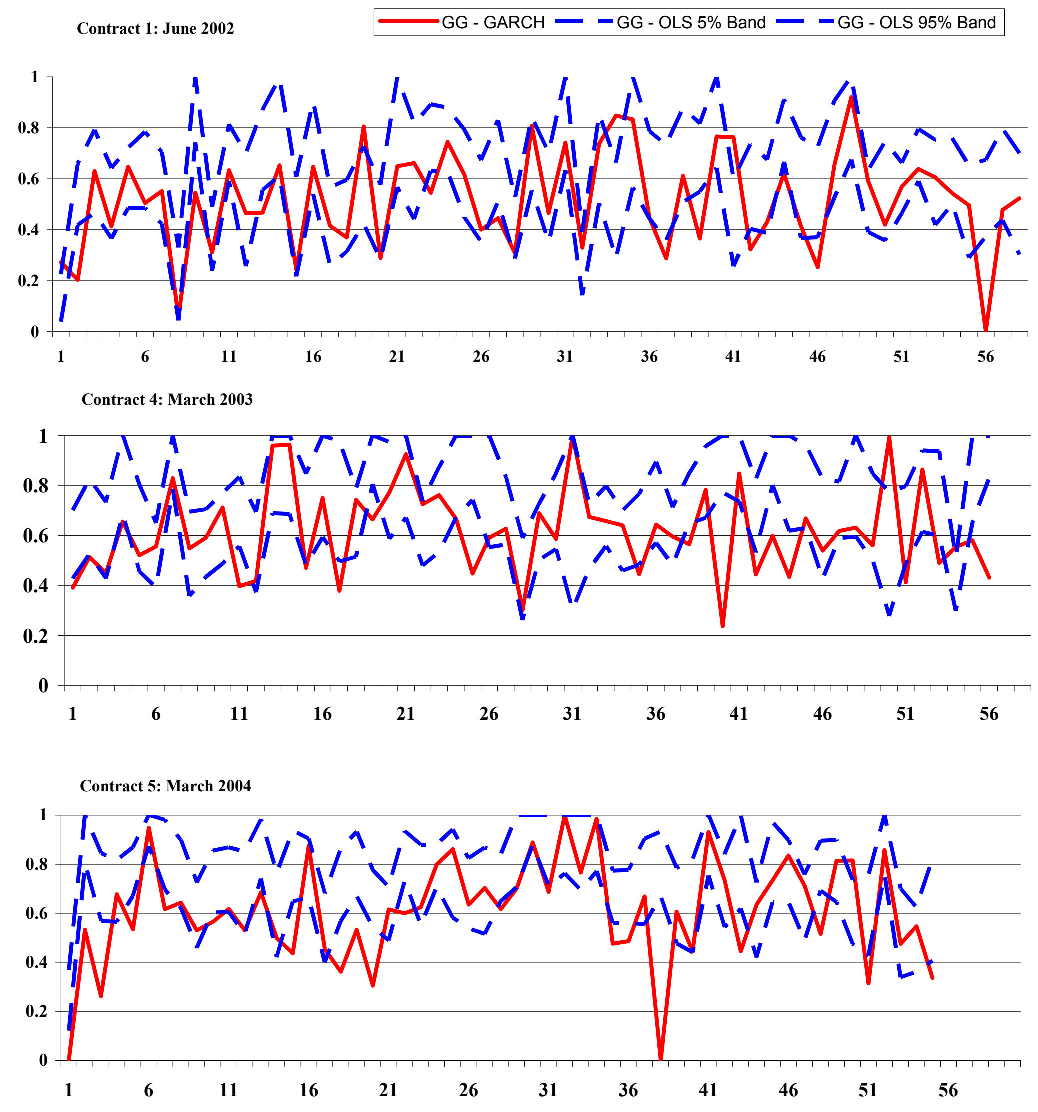

Figure 4
Average Impulse Responses using OLS-Full Day results