Centre for Financial Analysis & Policy

Working Paper no. 39:

Cojumping: Evidence from the US Treasury Bond and Futures Markets

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February 2011

Centre for
Financial Analysis
& Policy

UNIVERSITY OF
CAMBRIDGE
Judge Business School

Cojumping: Evidence from the US Treasury Bond and Futures Markets[*]

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25 February 2011

Abstract

The basis between spot and future prices will be affected by jump behavior in each asset price, challenging intraday hedging strategies. Using a formal cojumping test this paper considers the cojumping behavior of spot and futures prices in high frequency US Treasury data. Cojumping occurs most frequently at shorter maturities and higher sampling frequencies. We find that the presence of an anticipated macroeconomic news announcement is sufficient to change the probability of observing cojumps. Moreover, news surprises in non-farm payrolls, CPI, GDP and retail sales play a leading role in changing the probabilities of cojumps. However, surprises in non-farm payrolls also increase the probability of the cojumping tests being unable to determine whether jumps in spots and futures occur contemporaneously. On these occasions the market does not clearly signal its short term pricing behavior.

JEL Categories: C1; C32; G14

Keywords: US Treasury markets; High frequency data; Cojump test

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[*] We are grateful to Ross Adams for managing the database. We would like to thank Brett Inder, Petko Kalev, Michael McKenzie, Hashem Pesaran and an anonymous referee for constructive comments on this paper as well as participants at the Cambridge Finance Workshop, seminars at the Judge Business School, Monash University and the University of Tasmania, conferences at Warwick Business School and Princeton University for helpful discussions. Author contacts: Dungey, mardi.dungey@utas.edu.au, Hvozdyk, l.hvozdyk@cerf.cam.ac.uk.

1 Introduction

The joint behavior of spot and future prices for a single asset is particularly important in managing hedging positions; Stein (1961), Lien and Tse (2002) and recently Lee (2010). Prices in both contracts are known to move with news for many different asset types, and more recently, evidence from high frequency data strongly suggests that information arrival is often associated with price discontinuities, known as jumps; see Andersen et al. (2007a), Dungey et al. (2009a) and Lahaye et al. (2010)[1]. Intraday portfolio management involves recognizing and responding to such jumps. In particular, Lai and Sheu (2010) have demonstrated that the use of realized volatility measures, which incorporate jump behaviors, compiled from high frequency data delivers measurable improvements in hedging performance, while Todorov and Bollerslev (2010) estimate distinct betas for jump risk on individual stocks. These findings reinforce the potential gains from time varying hedge ratios, such as demonstrated in Brooks, Henry and Persand (2002). A time-varying hedge ratio will be particularly affected by cases where the basis is changed by non-contemporaneous jump behavior across spot and future markets.

This paper examines the joint behavior of the spot and futures markets for US Treasury bonds using a formal joint test of cojumping recently developed by Jacod and Todorov (2009). Cojumping refers to the occurrence of contemporaneous discontinuities in two price series, although in the formal test procedure the exact timing of cojumps is not identified. The spot and futures prices for US Treasuries are already known to jump individually; see for example Lahaye et al. (2010), Jiang et al. (2010), Jiang and Yan (2009), Dungey et al. (2009a), Andersen et al. (2007a)[2]. However, to our knowledge, the question of cojumping across spot and futures markets for the same assets is previously unstudied. In addition to considering the evidence for spot and futures cojumping, we additionally consider the jumping behavior across the term structure for each of the assets, extending the univariate test results in Dungey et al. (2009a). Contemporaneous jumps across the term structure are consistent with liquidity preference theory, while more idiosyncratic jumps support segmented markets.

The Jacod and Todorov procedure comprises two tests, conducted on individual price series in which jumps are already known to occur. One test has the null hypothesis of contemporaneous jumps across multiple asset prices (cojumping), while the other has the null hypothesis of disjoint jumps (or no cojumping). The tests build on the standard assumptions of a continuous price process with discrete interruptions (the jumps), where the multipower quadratic variation of the returns for the chosen time period, usually one day, can be consistently estimated by realized variance. Jacod and Todorov recognize that under the null of common jumps the ratio of realized variances at different sampling

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[1] See Aït-Sahalia (2002) for a discussion of identifying the characteristics of a diffusion process.

[2] The particular univariate testing frameworks include Barndorff-Nielsen and Shephard (2004, 2006), Aït-Sahalia and Jacod (2009), Lee and Mykland (2008) and Jiang and Oomen (2008).

frequencies will be the same, so that the hypothesis can be rejected when this is not the case. Alternatively, in the case of a null of disjoint jumps, the ratio of the realized variance to the square root of product of the quadratic returns of the individual asset returns tends to zero (that is there is no evidence that the movements occur together).

High frequency US Treasury spot prices are drawn from eSpeed, one of the two dominant ECNs trading these assets in the post-2000 era. Earlier work, such as Mizrach and Neely (2008) use data from the now superseded GovPX platform, which operated a voice over protocol. Corresponding data for the futures sample are obtained from the Chicago Mercantile Exchange, suitably transformed for nearest contract.

Working with 2, 5, 10 and 30 year maturity contracts we find evidence of cojumping between spot and futures prices, and that cojumping often occurs in response to the surprise component of scheduled US macroeconomic news announcements. There are more jumps in the futures contracts than the spot contracts, however, there are also periods when the spot market jumps but the futures market does not.

Given that the cojumping test proposed by Jacod and Todorov (2009) have two components, we find some periods where these tests are in conflict, so that one test suggests a cojump in the two assets and the other rejects its presence - that is one test suggests that jumps detected in each series occur contemporaneously on a given day, but the other test suggests they are separated in time. The extent of this is far greater than anticipated. We therefore confirm the sample properties of the tests via an extension of the Monte Carlo study of Jacod and Todorov (2009) which takes into account the highly correlated nature of spot and futures prices. As we find that the contradictory test results are not an artefact of the test behavior, we consider the influence of news. Simple tabulations suggest that the conflicting results in the spot and futures pairs occur predominantly in the presence of negative surprises for US non-farm payrolls data. Formal regression analysis confirms that macroeconomic news arrival influences not only the probability of a jump, a result found in previous papers, but also the probability of observing an contradictory result. In these contradictory instances the hedging signals are unclear, as the tests are unable to reveal whether the basis has changed due to a jump in one asset, implying a potential arbitrage opportunity in the other asset, or due to different sized contemporaneous jumps in both assets. In particular, the tests cannot distinguish whether the data are subject to contemporaneous price discontinuities in the two markets, or whether the price discontinuities are separated in time. This likely reflects uncertainty around the news announcement, leading to moves which are inconsistent with the underlying continuous data generating process as the market attempts to establish a new equilibrium. For an intraday speculator or portfolio manager, it is potentially important to recognize that these periods of confusion, and hence opportunity, occur primarily in association with news releases, and particularly in response to the release of surprises in non-farm payrolls data.

The paper is organized as follows. Section 2 presents formal jump test methodologies. The data are described in Section 3 and the results of the cojumping tests are discussed in Section 4. In Section 5 the small sample properties of the jumps test are examined in a Monte Carlo with correlated prices. The relationships between cojumping and news, and contradictory test result occurrences and news are analyzed in Section 6. Finally, Section 7 concludes.

2 Methodology

2.1 Univariate jump test

The jump days for each series are determined using the univariate jumps test of Barndorff-Nielsen and Shephard (2006), henceforth BNS, which is a specific case of the more general proposal of Aït-Sahalia and Jacod (2009)[3]. Assume that an individual asset price, x_{it}, is an Itô semimartingale process

$$x_{it} = \int_0^t b_s ds + \int_0^t \sigma_s dW_s + \sum_{j=1}^{N} c_{jt}, \tag{1}$$

where x_t represents the price of the asset at time t, and the right hand side terms represent a continuous, locally bounded variation process, b_t, a strictly positive stochastic volatility process, σ_t, W_t is Brownian motion and the final term is a jump process where c_{jt} assumes a Poisson arrivals process with N possible jump occurrences. Returns for δ intervals are given by $r_{t+j\delta,\delta} = x_{t+i\delta} - x_{t+(j-1)\delta}$. The realized variance for each period t (one day in the application here) is sum of squared δ period returns which converges as $\delta \to 0$ to the true quadratic variation and squared jumps,

$$RV_{t+1}(\delta) = \sum_{i=1}^{1/\delta} r_{t+i\delta,\delta}^2 \to \int_0^t \sigma_s^2 ds + \sum_{0<s\leq t} c_s^2, \tag{2}$$

while the product of absolute adjacent δ period returns, or bipower variation converges to quadratic variation,

$$BV_{t+1}(\delta) = \mu_1^{-2} \sum_{i=2}^{1/\delta} \left| r_{t+i\delta,\delta} \right| \left| r_{t+(i-1)\delta,\delta} \right| \to \int_0^t \sigma_s^2 ds,$$

where $\mu_1 = \sqrt{2/\pi}$ is a normalizing coefficient.

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[3] Alternative possibilities include the Lee and Mykland (2008) test, and the Jiang et al. (2010) procedure based on Jiang and Oomen (2008) which have the advantage of revealing the timing of the intraday jumps. However, Monte Carlo experiments revealed that these approaches were oversized and underpowered in detecting contemporaneous and disjoint jumps in intraday data. See also footnote 5.

The BNS test recognizes that as $\delta \to 0$ the difference between realized volatility and bipower variation converges to a jumps only component

$$RV_{t+1}(\delta) - BV_{t+1}(\delta) \to \sum_{0<s\leq t} c_s^2,$$

which is modified to account for potential negative observations and serial correlation following Huang and Tauchen (2005) as

$$JS_{t+1}(\delta) = \left(RV_{t+1}(\delta) - BV_{t+1}(\delta)\right) / \left((\mu_1^{-4} + 2\mu_1^{-2} - 5)\delta \int_t^{t+1} \sigma^4(s)ds \right)^{-1/2} \sim N(0,1). \quad (3)$$

2.2 Bivariate jump test

While Barndorff-Nielsen and Shephard (2004) extend the concepts of bipower variation and realized variance to multivariate equivalents, the corresponding multivariate test is currently incomplete. An alternative is the extension to the bivariate case presented in Jacod and Todorov (2009). The assumed structure for the pricing process of the financial market assets is now expressed for a vector, x_t, where for convenience x_t represents the bivariate case of the current paper. Formally,

$$\begin{aligned} x_t &= x_0 + \int_0^t b_s ds + \int_0^t \sigma_s dW_s + \int_0^t \int \kappa' \circ \theta\left(s,x\right)\left(\mu - v\right)\left(ds,dx\right) \\ &\quad + \int_0^t \int \kappa' \circ \theta\left(s,x\right)\mu\left(ds,dx\right), \end{aligned} \quad (4)$$

where b_t is the deterministic drift coefficient, W_t is a Brownian motion, and μ is a Poisson random measure (the jumps). The intensity of the jumps is v with a truncation function $\kappa\left(x\right) = x$ on a neighborhood of 0. Both b_t and θ are 2-dimensional processes in the 2 asset case and the 2×2 variance-covariance matrix of the returns, σ_t, is non-trivially assumed to evolve with the same Itô semimartingale form as (4), that is there are drift and jump terms in the evolution of the volatility.

There are three complementary sets to which the observed price paths may belong: Ω_t^J, when the series cojump (that is both series jump contemporaneously), Ω_t^D when the individual series jump but do not cojump, known as disjoint jumps and Ω_t^C, when at least one of the series is continuous, that is displays no jumps. Jacod and Todorov eliminate Ω_t^C from consideration by pretesting individual series for the presence of jumps using univariate jump test series – so that interest is focussed purely on the jumping series.

The formal tests of jumps across multiple series are based on the use of the power variation estimators, where $r_{t+j\delta,\delta}$ is the vector of return series:

$$V(f,\delta)_t = \sum_{j=1}^{[1/\delta]} f(r_{t+j\delta,\delta}) \text{ and } V(g,\delta)_t = \sum_{j=1}^{[1/\delta]} g(r_{t+j\delta,\delta}).$$

The first test uses a null of common jumps, and compares the power variation of the returns series at two different sampling frequencies (scales), δ and $k\delta$ where k is a positive integer. The test statistic, $\Phi_t^{(J)}$ converges to one under the null of common jumps:

$$\Phi_t^{(J)} = \frac{V(f, k\delta)_t}{V(f, \delta)_t} \xrightarrow{P} 1,$$

where

$$V(f, \delta)_t \xrightarrow{P} \hat{B}_t = \sum_{s \leq t} (r_{1,s})^2 (r_{2,s})^2.$$

The second test has a null of disjoint jumps (or equivalently there are no contemporaneous jumps) and the test statistic, $\Phi_t^{(D)}$, has the form

$$\Phi_t^{(D)} = \frac{V(f, \delta)_t}{\sqrt{V(g_1, \delta)_t V(g_2, \delta)_t}} \xrightarrow{P} 0$$

where

$$V(g_i, \delta)_t \xrightarrow{P} \hat{B}'_{i,t} = \sum_{s \leq t} (r_{i,s})^4.$$

The tests have critical regions based on $C_t^{(J)} = \left\{ \left| \Phi_t^{(J)} - 1 \right| \geq \frac{Z_t^{(J)}(\alpha)\sqrt{\delta}}{V(f,\delta)_t} \right\}$ and $C_t^{(D)} = \left\{ \Phi_t^{(D)} \geq \frac{\delta\left(Z_t^{(D)}(\alpha) + \hat{A}_t\right)}{\sqrt{V(g_1,\delta)_t V(g_2,\delta)_t}} \right\}$, where $Z_t^{(J,D)}(\alpha)$ are the normalized order statistics based on the normalized truncated power variation, and $\hat{A}_t$ is an alternative truncated power estimator (Jacod and Todorov, 2009).

3 Data description

US Treasury markets are large in terms of turnover per trading day. Futures trade volume is greater than spot, but the turnover in the spot market itself is substantial; an average trade volume of \$US524.7 billion per day was recorded in 2006 (see Spiegel, 2008). In this paper the data set for spot trade in US Treasury bonds is drawn from the Cantor-Fitzgerald eSpeed trade file and comprises tick by tick transaction prices for the 2, 5, 10 and 30 year US Treasury bonds. The eSpeed platform is one of two dominant ECNs in this market, the other being ICAP's BrokerTec, and the characteristics of the trading volume on the two platforms are not significantly different (compare the data in Dungey et al., 2009a and Jiang et al., 2010). Futures contracts on the same maturity Treasury bonds are sourced from the Chicago Mercantile Exchange and are also tick by tick data for transactions on that platform. The common span of these data sets is from January 2, 2002 to December 31, 2006 with a trading day defined as the period from 7:30a.m. to 5:30p.m. New York time. Weekends and public holidays are excluded from the sample. The market is very liquid – for example only 4 percent of the 5 minute intervals contain no spot trade in the 5 year bond.

Discretized spot and futures data are constructed such that the last transaction in an interval indicates the price at the end of the interval. A number of different sampling frequencies have been applied in studies of jumps thus far. Lahaye et al. (2010) use 15 minutes, Huang and Tauchen (2005) and Andersen et al. (2007a) sample at 5 minute intervals, while Dungey et al. (2009a) produce results for a number of different frequencies. Unfortunately, the optimal sampling frequency tests proposed by Bandi and Russell (2006) give no guidance on the appropriate means of choosing sampling frequency for multiple series considered contemporaneously, particularly in the case of different trade intensities as in the current problem. Consequently, we consider three sampling frequencies, namely 1, 5 and 10 minute intervals.

Examples of the intraday returns and potential jump behavior of the data are given in Figure 1, which presents 5 minute returns in 5 year spot and futures data for two particular days where US non-farm payrolls data were released to the market. The Figure shows that there are clear disruptions in the price processes at the time of those announcements.

Descriptive statistics for the intraday returns data are presented in Table 1. The largest average returns are obtained for the 30 year bonds (0.0003%) at 10 minute intervals. As the sampling frequency increases, the average returns decrease, with the futures returns approaching 0 faster than the corresponding spot transactions. Futures returns tend to be more volatile than spot returns. For example, at 5 minute intervals, the standard deviation of the 5 year and 10 year maturity futures is almost 8 times the standard deviation of the spot return (0.024 versus 0.170 and 0.040 versus 0.276). The highest standard deviation is obtained for the 30 year securities with the volatility in the futures again higher than that in the spot returns.

4 Empirical tests

4.1 Univariate test

The appropriate sample period to search for jumps is taken to be one trading day. The filter for days where individual series jump is the BNS univariate jump test.

The application of the univariate jumps tests reveals a considerable number of days when both spot and futures contracts of the same maturity exhibit jumps. The results are summarized in Table 2, which gives the number of days on which a jump is detected and the corresponding rejection frequency for the null hypothesis of no univariate jumps for each series. The rejection frequencies of the null hypothesis of no univariate jumps are generally higher for futures contracts than for the corresponding maturity spot contracts (except for the 30 year futures at the 10 minute interval). It is also apparent that as sampling frequency increases the number of test rejections increases. This result is especially striking for the 1 minute sampling frequency where rejection rates are all over 85%. This is a common result and usually attributed to the increased influence of microstructure noise in more frequently sampled data. It is difficult to differentiate statistically between noise and information or to choose optimal sample frequencies as previously discussed. The rejection rates for the null of no jumping in the futures contracts decrease monotonically as the maturity increases from the 2 year to 30 year. This also holds for spot contracts at 10 minute intervals but is mixed at higher frequencies. It is well known that the volatility of the more liquid short-dated securities exceeds that of the longer term securities, and this represents a possible explanation of the negative association between jump frequency and maturity.

We are interested in days when both spot and futures contracts of the same maturity jump. These days are then used as the basis for the test of whether or not those jumps occur contemporaneously (cojump). The number of days where both series jump is recorded in the penultimate column of Table 2, and the proportion of the total sample days this represents in the final column. The numbers vary depending on the sampling frequency: for the 30 year maturity pair the common days are 87 at the 10 minute sampling frequency and 1106 at the 1 minute frequency. Common jump days are taken as the sample for the cojumping tests.

4.2 Bivariate test: bond and futures maturity pairs

Cojumping occurs when two prices jump contemporaneously, where the cojumping tests are applied to days where both series exhibit jumps individually. We test for cojumping behavior across spot and futures contracts of the same maturity, and secondly on pairs of assets of differing maturity within the term structure of the spot or futures markets. Hence there are 4 maturity pairs in the spot and futures matched maturity sample: 2, 5, 10 and 30 year contracts, and 6 maturity pair combinations within each of the spot and futures datasets: 2 and 5, 2 and 10, 2 and 30, 5 and 10, 5 and 30, and 10 and 30 year maturities.

The findings of the two cojumping tests, $\Phi_t^{(J)}$ and $\Phi_t^{(D)}$, for each bond and futures maturity pair are presented in Table 3 for 1, 5, and 10 minute sampling frequencies. Column (1) gives the number of days on which the null of cojumping is rejected using the $\Phi_t^{(J)}$ test, and column (3) gives the number of days when the null of no cojumping is rejected using the $\Phi_t^{(D)}$ test. When $\Phi_t^{(J)}$ is accepted and $\Phi_t^{(D)}$ rejected the tests consistently find cojumping, as shown in column (5). The occurrences when the tests consistently find no cojumps, when $\Phi_t^{(J)}$ is accepted and $\Phi_t^{(D)}$ rejected, are shown in column (7).

Consider first the results of the tests for spot and futures maturity pairs. Rejection of the null of cojumping increases monotonically with increasing maturity in the Treasury bonds – which means there is more evidence of cojumping at shorter maturities. This result is consistent with the univariate outcomes that there is more jumping in shorter dated maturities than longer dated, associated with their generally higher volatility. To illustrate consider the 1 minute frequency in Table 3. The null of cojumping, using $\Phi_t^{(J)}$, is rejected in 4.4% of the total 1230 days for the 2 year maturity, and 61.5% of 1230 days for the 30 year maturity. The 5 and 10 year maturities lie between these extremes. The same pattern may be found for other sampling frequencies. The rejection frequency for the null of common jumps also seems to largely decline with sampling frequency, although this is not strongly evident in the 2 year maturity. In summary there is more evidence of cojumping at shorter maturities and higher sampling frequencies using the cojumping test.

The disjoint test, however, based on the null of disjoint jumps, $\Phi_t^{(D)}$, does not display a monotonicity with maturity. For example, at the 1 minute frequency in Table 3 the null of disjoint jumping is rejected in 88.5% of 1230 days for the 2 year maturity, and 71.4% of 1230 days for the 5 year maturity – but for the 30 year maturity the disjoint jumps are rejected in 73.2% jump days. However, there is evidence of monotonicity with the sampling frequency. Using the 5 year maturity as an example, the rejection of the disjoint null decreases from 71.4% of days at 1 minute sampling to 9.6% of days at 10 minute sampling. Thus there is less evidence of disjoint jumps at higher sampling frequencies. One possible explanation for this observation is that the greater number of observations used at higher frequency improves the sampling properties, while a non mutually-exclusive alternative is that noise masks an underlying problem.

The two cojumping tests have an area of disagreement, when either both reject their respective null hypotheses or both accept. The prevalence of these occurrences are recorded in columns (9) and (11) of the tables, and are clearly well in excess of the type I and type II errors expected. We consider this issue more fully in Section 5.

4.3 Bivariate test: term structure

Results of the cojumping tests for the term structure are summarized for the three sampling frequencies in Table 4 for both spot and futures contracts. The left and right hand side panels of the Table demonstrate the results when both nulls indicate joint or disjoint jumps for all maturity pairs across the yield curve. Joint jumps occur most frequently at the short end of the maturity structure comprising the 2 and 5 year maturities. This holds for both spot and futures markets regardless of the sampling frequency. For instance, Table 4 shows that the 2 and 5 year bonds are cojumping on 976, 371 and 153 days out of total 1230 days at 1, 5 and 10 minute sampling frequencies, respectively, showing the highest proportions among all possible maturity pairs. The 2 and 30 year maturities jump jointly fairly frequently as well with the proportions higher than the ones of the short maturities. As in Dungey et al. (2009a), the term structure demonstrates more jumping behavior at the ends than in middle maturities, reflecting elements of both liquidity preference and preferred habitat theory.

The smallest number of days containing joint jumps is found for the maturity pairs when one of the assets represents the longest end of the maturity structure – 30 and 10 year maturity pairs and 30 and 5 year maturity pairs. At the same time, 30 year maturity in conjunction with the 5 or 10 year maturities tend to jump disjointly more often than other pairs. The cases when both nulls disagree have patterns similar to the ones in Section 4.2.

To examine the results of the Sections 4.2 and 4.3 more carefully the next two sections explore first, the sampling properties of the tests by extending the Monte Carlo experiment of Jacod and Todorov (2009) to more closely resemble the characteristics of the current problem, and second, the relationship of the cojumping behavior with news announcements in US markets. This builds on a large existing body of work on the relationship between price changes in US Treasury markets and scheduled macroeconomic news releases; see Fleming and Remolona (1999), Green (2004), Simpson and Ramchander (2004), Andersen et al. (2007b).

5 Finite sample properties

5.1 Simulation design

Jacod and Todorov (2009) examine the finite sample properties of their test under the assumption that the two series are uncorrelated and have the same jump intensity. The data considered in this paper are highly correlated and have different jump intensities; futures are more intensely traded than spot contracts. Consequently, we extend the Monte Carlo of Jacod and Todorov (2009) accordingly. Two data generating processes for the log price process, x_t are implemented. The first is a constant volatility jump diffusion model originally designed by Jacod and Todorov (2009), and the second a stochastic volatility jump diffusion model, as in Andersen et al. (2010), Chernov et al. (2003), Andersen et al. (2002). The constant volatility process, CVP, is defined as:

$$\textbf{CVP:}\quad dx_{i,t} = \sigma_i dW_{i,t} + \alpha_i \int_{\mathbb{R}} x_i \lambda_i(dt, dx_i) + \alpha_3 \int_{\mathbb{R}} x_i \lambda_3(dt, dx_i),\ i = \{1, 2\}, \tag{5}$$

where $W_{i,t}$ is a Brownian motion, $cor(W_1, W_2) = \rho$; λ_1, λ_2 and λ_3 are the Poisson measures; σ_i is a constant volatility factor.

The stochastic volatility jump diffusion model, SVP, has the form:

$$\textbf{SVP:}\quad \begin{array}{l} dx_{i,t} = \exp(\beta_0 + \beta_i v_{i,t}) dW_{i,t} + \alpha_i \int_{\mathbb{R}} x_i \lambda_i(dt, dx_i) + \alpha_3 \int_{\mathbb{R}} x_i \lambda_3(dt, dx_i) \\ dv_{i,t} = \alpha_v v_{i,t} dt + dW_{v_i,t},\ i = \{1, 2\}, \end{array} \tag{6}$$

where W_t is the Brownian motion; $cor(W_i, W_{v_i}) = \rho_i$ is the leverage correlation; $cor(W_1, W_2) = \rho$ is the correlation between returns; $v_{i,t}$ is the stochastic volatility component; λ_1, λ_2 and

λ_3 are the Poisson measures. Following Jacod and Todorov (2009) we set $\alpha_v = 0.1$, $\beta_0 = 0$, $\beta_i = 0.125$ and in line with Veraart (2010), $\rho_i = -0.62$.

The three jump components of the process (5) are represented by two disjoint jump components and a common jump component premultiplied by α_1, α_2 and α_3, respectively. The number of jumps in each component is simulated from a Poisson distribution with parameter λ and is uniformly distributed on the whole time interval. The parameter λ is chosen to reflect the lowest of the rejection frequencies in the univariate tests of the data given in Table 2. The jump sizes are drawn from a $N(0,1)$ distribution. As US Treasury futures and spot prices are characterized by high correlations we trial values of ρ, the correlation of the continuous part of the process, of 1.00 and 0.95. The results were not qualitatively different and only the $\rho = 1$ outcomes are reported here. We simulate 5000 replications from the processes (5) and (6) with one increment per minute for a trading day of 600 minutes, consistent with the dataset in Section 4[4].

The first three columns of Table 5 shows the parameter values of the 16 cases we consider when $\rho = 1$. Intensities λ_1 and λ_2 corresponding to the disjoint components of the DGP (5) are 1:1 (this is the case studied by Jacod and Todorov, 2009), 2:1, 5:1 and 10:1, and the intensity λ_3 is equal to λ_1 in all simulation scenarios. Constant volatility factors σ_1 and σ_2 are equal to 8×10^{-5} in all simulations.

5.2 Size and power

Table 5 reports results for the case of the 1% true size tests. This significance level is reported for consistency with the application, but simulations at higher significance levels produce similar analytical results. The BNS univariate jumps test reported in columns (4) and (7) of Table 5 is oversized, consistent with literature on the univariate jump test properties (e.g. Huang and Tauchen, 2005), and more so in the SVP than CVP, which may be due to a volatility feedback effect when negative returns are associated with higher volatility. As the intensity of the jumps increases, the test size rises, indicating that the relatively small jumps are difficult to distinguish from the Wiener process.[5]

Under the null of cojumping the bivariate test is oversized for both DGPs as reported in columns (5) and (8) of Table 5. This improves with smaller values of the α parameters. The disjoint jumping test is undersized, as reported in columns (6) and (9).

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[4] To make the CVP and SVP processes comparable across simulations the Brownian motion innovations to the price process of equation (6) are rescaled by a factor of 120.

[5] A referee suggested that we consider replacing the BNS test with an alternative which allows detection of the timing of the jumps - two possibilities are the procedure in Jiang et al. (2010) and the Lee and Mykland (2008) tests. We also conducted Monte Carlo experiments with the specification reported in the text and found that the size and power results for these tests in locating contemporaneous or disjoint jumps were poor. In particular they were oversized and underpowered. We considered the performance of the Aït-Sahalia and Jacod (2009) test which was found to consistently overreject the null of no jumps - a consequence of the relatively lower liquidity, and hence lower sampling frequency, than their examples. The Monte Carlo results are available from the authors on request.

Table 5 also presents the power properties of the three test statistics. Larger jump size and higher jump intensity have a positive effect on the univariate test power as shown in Columns (10) and (13). The cojumping test has relatively low power for high values of the α parameters, and as with the size results for this test, power improves as the sizes of the jump, the α parameters, increase. The disjoint test has good power in all experiments, columns (12) and (15).

The results of the Monte Carlo experiment have confirmed earlier work that the BNS univariate test is somewhat oversized. The Jacod and Todorov common jumps test is also oversized with both size and power improved by higher jump sizes, while the disjoint test has good power properties, but is somewhat undersized. These results are consistent with those at 5% and 10% significance levels. These Monte Carlo results do not suggest that the contradictory results between the two tests observed in Section 4.2 are the result of test performance. Consequently, we next turn to relating the occurrence of jumps, and contradictory results in the bivariate jumps tests, to the presence of news announcements.

6 Cojumps and news

It is well known that risk associated with Treasuries increases in response to macroeconomic news (Nippani and Smith, 2010), and that jumps often occur in association with a news event, in particular with surprises associated with prescheduled US news releases, see Lahaye et al. (2010), Andersen et al. (2007a, b). We use a set of 23 major US macroeconomic news announcements, consistent with Simpson and Ramchander (2004) and Dungey et al. (2009a)[6]. Of the 1230 trading days, 702 days, or 57%, contain scheduled macroeconomic news announcements.

The news surprise data for the announcements are drawn from Bloomberg and standardized across the sample. A simple cross tabulation with the jump test results suggests a strong correlation between days where jumps are detected and days which contain non-farm payrolls announcements. Non-farm payroll releases are known to be the news release which most affects US Treasury markets; Fleming and Remolona (1999) and Dungey et al. (2009a), although Jiang and Yan (2009) find PPI as their most important event. Hence it is not surprising that if arbitrage opportunities exist between futures and spot markets they are likely to occur around surprises emanating from non-farm payrolls data. In the current sample the non-farm payrolls data were released 59 times, producing a distribution of surprises shown in Figure 2. There were more negative than positive surprises, but no particularly large negative outlier is detected.

To formally evaluate the relationship between jump days and prescheduled news an-

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[6] The news announcements are: auto sales, business inventory, capacity utilization, construction spending, consumer credit, CPI, durable goods orders, factory orders, GDP, hourly earnings, housing starts, industrial production, leading indicators, new home sales, non-farm payrolls, personal consumption, personal income, PPI, retail sales, trade balance, unemployment, US NAPM, US Treasury Budget.

nouncements, we estimate a panel logit model on the probability of observing either a joint jump day, JD_{it}, or the probability of observing a conflicting day, CD_{it}, (i.e. the day when two bivariate nulls disagree) for maturities $i = 2, 5, 10, 30$ for $t = 1, ..., 1230$. In the initial specification we examine whether the presence of news, denoted by the variable $News_t$ which takes the value of 1 in the presence of news and 0 otherwise, is significant as a determinant of the probability of jumps or conflicting results. To account for possible effects of futures contract rollovers a dummy, $Exp_{i,t}$ equals one on the last day of trade for a given futures contract and zero otherwise. Two such dummies are necessary as expiry dates are the same for 10 and 30 year contracts and for 2 and 5 year contracts[7]. Day of the week dummies variables D_{jt}, $j = 1, 2, 3, 4$ are included, normalizing on Friday. Different maturities have different jump activities therefore we specify a random effects model that accounts for heterogeneity between different maturities[8]:

$$\begin{aligned} JD(CD)_{it} &= \beta_0 + \beta_1 News_t + \beta_3 Exp_{it|i=2,5} \qquad (7) \\ &\quad + \beta_4 Exp_{it|i=10,30} + \Sigma_{j=5}^{8} \beta_j D_{jt} + \varepsilon_{it}, \\ \varepsilon_{it} &= \tau_i + e_{it}, \qquad (8) \end{aligned}$$

where τ_i and e_{it} are two *iid* series with zero mean and constant variances. To extend this further, the $News_t$ variable is supplemented by the standardized surprise in non-farm payrolls releases, NFP_t (shown in Figure 2), and the standardized news surprise for all other news announcements, $Surp_t$.

$$\begin{aligned} JD(CD)_{it} &= \beta_0 + \beta_1 News_t + \beta_2 NFP_t + \beta_3 Surp_t + \beta_4 Exp_{it|i=2,5} \\ &\quad + \beta_5 Exp_{it|i=10,30} + \Sigma_{j=6}^{9} \beta_j D_{jt} + \varepsilon_{it}, \\ \varepsilon_{it} &= \tau_i + e_{it}, \qquad (9) \end{aligned}$$

Similarly, we estimate two panel logit models for the term structure of US Treasury bonds and futures, where the dependent variable JD_{it} denotes joint jump days between maturities i and l. An additional independent variable in equation (10) is a set of maturity dummies, M_{jt}, $j = i, l$, with the 30 year bond taken as the omitted category. These take the of value 1 when either of the maturity pair under consideration involves that maturity, so for jumps considered in the combination of the 2 and 5 year contracts, $M_{2,t} = M_{5,t} = 1$.

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[7] The 2 and 5 year contracts expire on the last business day of the contract month, the 10 and 30 year contracts expire 7 business days before the last business day of the contract month. See www.cmegroup.com for further details. A number of robustness checks were conducted for the expiry dummy. Examination of the trade data suggests increased volume and volatility some 20 ± 2 trading days before the expiry of the 2 and 5 year contracts and some 15 ± 2 days before the expiry of the 10 and 30 year maturity contracts. Dummies based on these timings were also insignificant, and are not reported in the paper.

[8] The Hausman test confirms the choice of a random effects specification.

Futures contract expiry dummies are also included in the specification for futures only:

$$\begin{aligned} JD_{it}(CD_{it}) &= \beta_0 + \beta_1 News_t + \beta_2 NFP_t + \beta_3 Surp_t + \beta_4 Exp_{it|i=2,5} \\ &\quad + \beta_5 Exp_{it|i=10,30} + \Sigma_{j=6}^{9} \beta_j D_{jt} + \Sigma_{j=10}^{12} \beta_j M_{jt} + \varepsilon_{ilt}, \\ \varepsilon_{it} &= \tau_i + e_{it}, \end{aligned} \tag{10}$$

Table 6 reports results of estimating equations (7) and (10) with the bivariate $News_t$ dummy. They reveal a significant influence of the presence of scheduled macroeconomic news on the likelihood of a cojumps occurring on that day. For the term structure, a scheduled news announcement increases the probability of a joint jump on that day by 2.2% in the spot market but decreases it by 1.5% in the futures market. The presence of macroeconomic news also results in a statistically significant 2.7% increase in the probability of the bivariate tests disagreeing for spot and futures pairs. Across maturity pairs, the presence of scheduled macroeconomic news has a statistically insignificant impact on the likelihood of either joint or disjoint jumps on that day. However, the presence of news does result in a statistically significant increase in the probability of conflicting evidence on cojumping. In the case of the maturity pairs news the impact is a 2.7% increase in the probability of a conflicting result, and for the term structure an increase of 5.3% for spot and 1.8% for futures.

The significance of the day of the week dummies varies, but in general Mondays have a significant impact on the probability of observing a joint jump, confirming the information that arrives after the weekend is important in explaining the jumps.

When the $News_t$ dummy is augmented by the news surprise for all news announcements, as in equations (9) and (10) it retains its statistical significance. However, a further decomposition, reported in Table 7 reveals greater detail, by allowing for 8 separate news surprise variables and a composite variable for the remaining 15 surprises. The 8 news releases selected were identified as the most influential news events in the studies by Fleming and Remolona (1999), Simpson and Ramchander (2004) and Dungey et al. (2009a). Additionally, the specification allowed for an asymmetric response to positive and negative non-farm payroll surprises.

Table 7 reveals that in the cases of either the spot or futures term structure, the presence of a news announcement is sufficient to change the probability of a joint jump across the term structure, while this is not the case for the maturity matched pairs[9]. The term structure of the futures market reveals no relationship with any individual news announcement, while maturity matched pairs show a reduced probability of a joint jump day in association with GDP surprises. In the spot term structure results the surprise

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[9] Jiang, Lo and Verdelhan (2010) suggest that liquidity factors may also be important in promoting jump behaviour, however, the expandable limit order nature of the eSpeed database makes the construction of an order book similar to that used in their analysis difficult in this case, see Dungey et al. (2009b) and Boni and Leach (2004) for a description of the expandable limit order book.

components of the retail sales significantly increase the probability of a joint jump day, while CPI, GDP and retail sales decrease the probability of a joint jump. Non-farm payrolls surprises decrease the probability of observing a joint jump day in the spot term structure - the surprises are signed so that a positive coefficient on either positive or negative surprises corresponds to an increase in the probability of a jump. A Wald test reveals that the coefficients on negative and positive jumps are significantly different in this case, so that positive surprises decrease the probability of a joint jump day more than negative surprises.

The most interesting result, however, is in the case where the tests of joint and disjoint jumping behavior disagree; that is when the tests cannot statistically distinguish whether jumps have occurred contemporaneously or otherwise. The probability of observing conflicting results is increased on days with a news release, and specifically on days with non-farm payrolls surprises. The evidence for conflicting jumps days shows that in each of the three cases positive non-farm payrolls surprises and negative payrolls increase the probability of observing a conflicting jump result. The coefficients on positive and negative surprises are significantly different for the futures term structure, where a positive surprise has a greater impact than a negative surprise. For the maturity matched pairs and spot term structure positive and negative surprises have the same impact. In other cases, news on the CPI and GDP reduces the probability of conflicting results for the spot term structure, while GDP news increases the probability in the futures term structure.

While the finding that news results are important is not unusual in the univariate jumps literature, this paper is the first to investigate news and cojumping behavior using a formal statistical test of cojumping. Non-farm payrolls have been previously documented as the most important macroeconomic news release affect US Treasury markets, and here they are shown to be highly influential in indicating revealed confusion about the behavior of price discontinuities between spot and futures markets. The presence of non-farm payroll surprises significantly increases the probability of it being difficult to statistically differentiate whether jumps are occurring contemporaneously or in a slightly separated manner. These cases are particularly interesting in that they represent periods when optimal hedging ratios may be changing rapidly and thus justify the intense scrutiny applied to these releases.

7 Conclusions

The presence of price discontinuities in high frequency financial market data is well documented in the univariate case. However, many interesting questions concern the presence of contemporaneous price disruptions across multiple assets. In a hedging framework an obvious question is the extent to which spot and future prices exhibit such behavior.

Recently, Jacod and Todorov (2009) have developed a bivariate test for contemporaneous within-day jumps across two series using a pair of tests – one of which has a null of cojumping and one of which the null of disjoint jumps, although the time of day is not identified. This paper considers the cojumping behavior of spot and future contracts for US Treasury contracts in maturity pairs, and across the term structure. The bivariate tests indicate that the detection of cojumping is increasing with sampling frequency. The test with the null of cojumping finds a monotonic relationship between cojumping and maturity structure – more cojumps are detected for lower maturity contracts in both futures and spot contracts for maturity pairs, or within the same market across the term structure.

As the two cojumping tests disagree more than statistically expected, the small sample properties of the tests were confirmed under the conditions of highly correlated series of different intensities present in this data. The disjoint test is found to be slightly undersized but with good power.

Prescheduled macroeconomic news events increase the probability of cojumping behavior. However, prescheduled news also increases the probability that the statistical tests are unable to distinguish whether price discontinuities in two assets are occurring contemporaneously or at distinct times within the day. The presence of surprises in non-farm payrolls is particularly associated with an increased probability that the two cojumping tests will disagree as to whether prices in the Treasuries market jumped contemporaneously; that is there is more confusion evident in the data in these cases. Overall, these results indicate the importance of non-farm payrolls releases to active portfolio management and speculative opportunities. The data do not clearly reveal the presence of cojumping or disjoint jumping around payrolls releases, meaning that there is ample reason to actively examine portfolio opportunities at these times.

A useful extension of this work will be to develop new cojumping statistics which are able to specify the timing of the jump events, particularly to reveal if price discontinuities on the news release days have discernible regularities. In particular, this will allow further exploration of the nature of the price impact of news arrival, such as whether the news surprise flows from futures to spot markets; see for example, Rosenberg and Traub (2006), Mizrach and Neely (2008) and Chen and Gau (2010)[10]. This is scope for future work.

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[10] We thank our referee for this useful suggestion.

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Table 1: Descriptive statistics for bond and futures returns across maturities and frequencies, 2002 – 2006

	BONDS				FUTURES			
Maturity	Mean	St Dev	Min	Max	Mean	St Dev	Min	Max
				1 minute sampling				
2 year	0.0000	0.006	-2.032	2.032	0.0000	0.054	-0.968	1.140
5 year	0.0000	0.012	–2.866	2.913	0.0000	0.151	-1.534	1.951
10 year	0.0000	0.018	-1.787	1.703	0.0000	0.260	-2.872	2.890
30 year	0.0000	0.033	-9.564	9.550	0.0000	0.271	-5.249	4.234
				5 minute sampling				
2 Year	0.0000	0.010	-0.517	0.470	0.0000	0.077	-0.968	1.140
5 Year	0.0001	0.024	-0.870	1.234	0.0000	0.170	-1.667	2.022
10 Year	0.0001	0.040	-1.723	1.509	0.0000	0.276	-2.604	2.639
30 Year	0.0002	0.071	-9.535	9.550	0.0000	0.290	-4.234	4.180
				10 minute sampling				
2 Year	0.001	0.014	-0.548	0.544	0.0000	0.084	-0.968	1.140
5 Year	0.002	0034	-1.103	1.326	0.0001	0.176	-1.693	2004
10 Year	0.002	0.056	-1.549	1.583	0.0000	0.286	-2.406	2.633
30 Year	0.003	0.086	-1.979	1.902	0.0001	0.300	-4.234	4.180

Figure 1: 5 minute returns for 5 year maturity US Treasury bonds and futures:

1 April 2005 7 February 2003

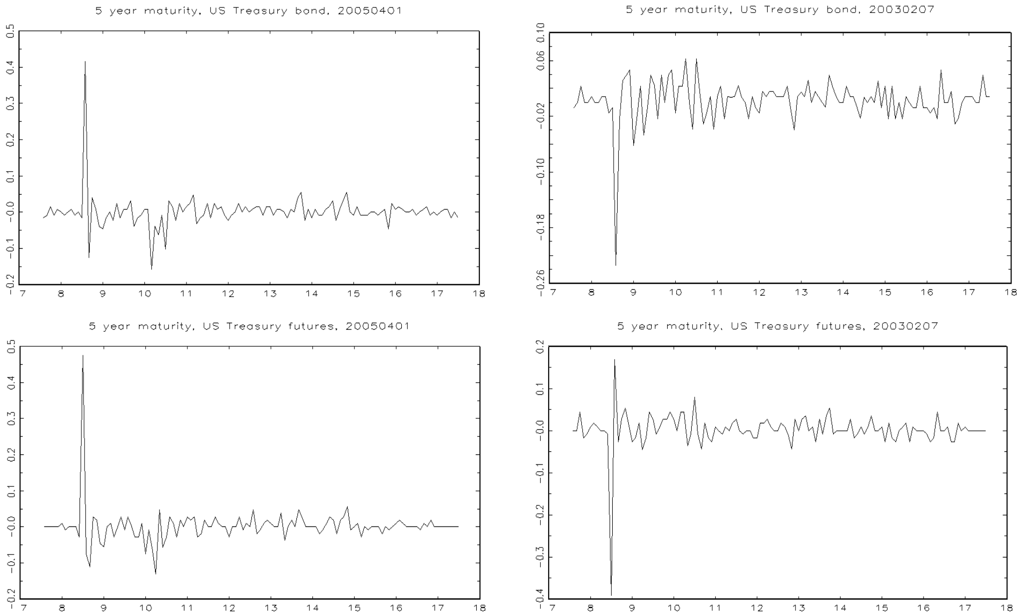

Table 2: Results of the univariate test for the US Treasury bond and futures, January 2002 – December 2006

	BOND		FUTURES		No. of	Prop. of
	No. of	Rejection	No. of	Rejection	common	common
Maturity	jump days	frequency	jump days	frequency	jump days	jump days
1 minute sampling:						
2 Year	1213	0.986	1222	0.993	1207	0.981
5 Year	1073	0.872	1198	0.974	1052	0.855
10 Year	1104	0.898	1166	0.948	1048	0.852
30 Year	1207	0.981	1128	0.917	1106	0.899
5 minute sampling:						
2 Year	916	0.745	1104	0.898	813	0.661
5 Year	451	0.367	728	0.592	293	0.238
10 Year	484	0.393	652	0.530	287	0.233
30 Year	574	0.467	586	0.476	298	0.242
10 minute sampling:						
2 Year	564	0.459	778	0.633	365	0.297
5 Year	298	0.242	347	0.282	142	0.115
10 Year	271	0.220	281	0.228	86	0.070
30 Year	273	0.222	250	0.203	87	0.071

Table 3: Results of the bivariate test for the maturity pairs of US Treasury bond and futures, January 2002 – December 2006

	Reject Ho:				Common arrival of jumps:		No common arrival of jumps:		Both nulls cannot be rejected		Both nulls can be rejected	
	Joint		Disjoint		Accept $\Phi_t^{(j)}$		Reject $\Phi_t^{(j)}$		Accept $\Phi_t^{(j)}$		Reject $\Phi_t^{(j)}$	
Maturity	Jumps, $\Phi_t^{(j)}$		Jumps, $\Phi_t^{(d)}$		Reject $\Phi_t^{(d)}$		Accept $\Phi_t^{(d)}$		Accept $\Phi_t^{(d)}$		Reject $\Phi_t^{(d)}$	
	No. (1)	Prop. (2)	No. (3)	Prop. (4)	No. (5)	Prop. (6)	No. (7)	Prop. (8)	No. (9)	Prop. (10)	No. (11)	Prop. (12)
					1 minute sampling							
2 year	54	0.044	1089	0.885	1047	0.851	12	0.010	106	0.086	42	0.034
5 year	189	0.154	878	0.714	749	0.609	60	0.049	114	0.093	129	0.105
10 year	466	0.379	806	0.655	471	0.383	131	0.107	111	0.090	335	0.272
30 year	756	0.615	900	0.732	308	0.250	164	0.133	42	0.034	592	0.481
					5 minute sampling							
2 year	34	0.028	708	0.576	683	0.555	9	0.007	96	0.078	25	0.020
5 year	77	0.063	243	0.198	187	0.152	21	0.017	29	0.024	56	0.046
10 year	158	0.128	226	0.184	111	0.090	43	0.035	18	0.015	115	0.093
30 year	241	0.196	246	0.200	52	0.042	47	0.038	5	0.004	194	0.158
					10 minute sampling							
2 year	43	0.035	328	0.267	290	0.236	5	0.004	32	0.026	38	0.031
5 year	65	0.053	118	0.096	69	0.056	16	0.013	8	0.007	49	0.040
10 year	53	0.043	75	0.061	30	0.024	8	0.007	3	0.002	45	0.037
30 year	74	0.060	71	0.058	12	0.010	15	0.012	1	0.001	59	0.048

Table 4: Results of the bivariate test for the maturity pairs of spot and futures markets, January 2002 – December 2006

	Spot						Futures					
Maturity	Common arrival of jumps: Accept $\Phi_t^{(j)}$ Reject $\Phi_t^{(d)}$		No common arrival of jumps: Reject $\Phi_t^{(j)}$ Accept $\Phi_t^{(d)}$		Both nulls can be rejected Reject $\Phi_t^{(j)}$ Reject $\Phi_t^{(d)}$		Common cannot be rejected Accept $\Phi_t^{(j)}$ Accept $\Phi_t^{(d)}$		No common can be rejected Reject $\Phi_t^{(j)}$ Reject $\Phi_t^{(d)}$		Both nulls can be rejected Reject $\Phi_t^{(j)}$ Reject $\Phi_t^{(d)}$	
	No.	Prop.	No.	Prop.	No.	Prop.	No.	Prop.	No.	Prop.	No.	Prop.
					1 minute sampling							
2 and 5	976	0.793	5	0.004	42	0.034	857	0.697	26	0.021	242	0.197
2 and 10	981	0.798	6	0.005	52	0.042	650	0.528	63	0.051	328	0.267
2 and 30	983	0.799	23	0.019	106	0.086	557	0.453	86	0.070	377	0.307
5 and 10	822	0.668	17	0.014	116	0.094	427	0.347	133	0.108	493	0.401
5 and 30	784	0.637	27	0.022	207	0.168	346	0.281	151	0.123	508	0.413
10 and 30	644	0.524	44	0.036	378	0.307	219	0.178	166	0.135	635	0.516
					5 minute sampling							
2 and 10	371	0.302	0	0.000	33	0.027	428	0.348	51	0.041	122	0.099
2 and 10	369	0.300	0	0.000	46	0.037	283	0.230	52	0.042	190	0.154
2 and 30	371	0.302	2	0.002	56	0.046	254	0.207	55	0.045	175	0.142
5 and 10	211	0.172	0	0.000	94	0.076	161	0.131	69	0.056	198	0.161
5 and 30	173	0.141	2	0.002	107	0.087	129	0.105	43	0.035	191	0.155
10 and 30	137	0.111	6	0.005	158	0.128	66	0.054	60	0.049	212	0.172
					10 minute sampling							
2 and 5	153	0.124	0	0.000	76	0.062	142	0.115	6	0.005	74	0.060
2 and 10	122	0.099	0	0.000	68	0.055	93	0.076	18	0.015	71	0.058
2 and 30	98	0.080	1	0.001	69	0.056	73	0.059	13	0.011	67	0.054
5 and 10	91	0.074	0	0.000	96	0.078	49	0.040	10	0.008	71	0.058
5 and 30	59	0.048	0	0.000	91	0.074	28	0.023	12	0.010	65	0.053
10 and 30	51	0.041	0	0.000	110	0.089	20	0.016	6	0.005	69	0.056

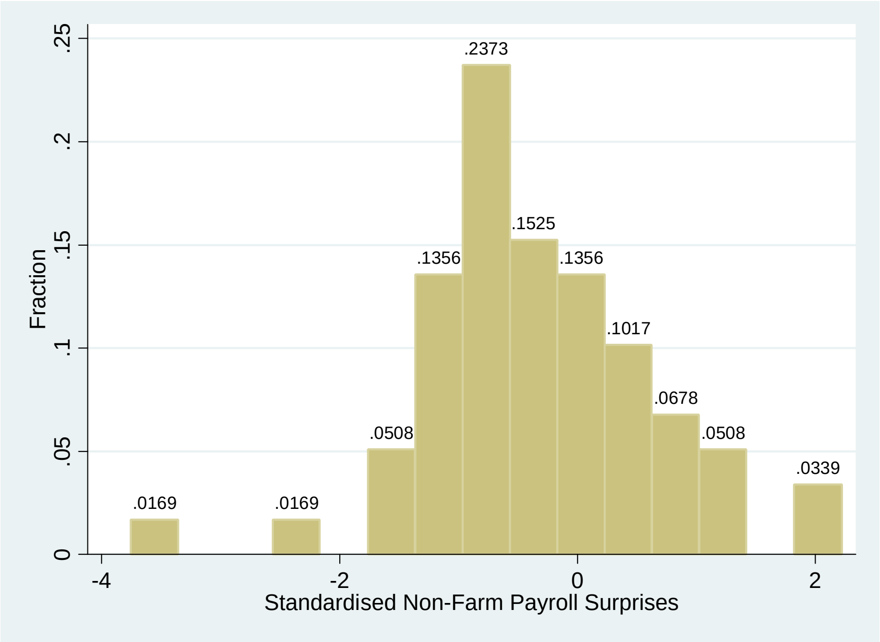

Figure 1: Distribution of the standardised non-farm payroll surprises, 2001 – 2006

Table 5: Size and power properties of the univariate and bivariate jump tests Based on an Asymptotic Size of 1%, Constant and Stochastic Volatility Models, Equivalent to 1 Minute Sampling Frequency, 5,000 Replications.

Parameters			Size						Power					
$\rho = 1$			CVP			SVP			CVP			SVP		
α_3	$\alpha_{1,2}$	$\lambda_{1:2}$	JS_t	$T_t^{(j)}$	$T_t^{(d)}$	JS_t	$T_t^{(j)}$	$T_t^{(d)}$	JS_t	$T_t^{(j)}$	$T_t^{(d)}$	JS_t	$T_t^{(j)}$	$T_t^{(d)}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
0.6	0.6	1:1	0.018	0.334	0.001	0.114	0.340	0.001	0.959	0.666	0.999	0.855	0.660	0.999
0.6	0.6	2:1	0.020	0.333	0.000	0.108	0.343	0.000	0.963	0.667	1.000	0.898	0.657	1.000
0.6	0.6	5:1	0.028	0.354	0.000	0.110	0.364	0.000	0.958	0.646	1.000	0.933	0.636	1.000
0.6	0.6	10:1	0.030	0.347	0.000	0.106	0.357	0.000	0.956	0.653	1.000	0.946	0.643	1.000
0.6	0.2	1:1	0.018	0.333	0.001	0.114	0.336	0.001	0.911	0.667	0.999	0.829	0.664	0.999
0.6	0.2	2:1	0.020	0.333	0.000	0.108	0.343	0.000	0.917	0.667	1.000	0.882	0.657	1.000
0.6	0.2	5:1	0.028	0.355	0.000	0.110	0.362	0.000	0.915	0.645	1.000	0.923	0.638	1.000
0.6	0.2	10:1	0.030	0.346	0.000	0.106	0.356	0.000	0.907	0.654	1.000	0.940	0.644	1.000
0.2	0.6	1:1	0.018	0.086	0.001	0.114	0.097	0.001	0.912	0.914	0.999	0.816	0.903	0.999
0.2	0.6	2:1	0.020	0.092	0.000	0.108	0.105	0.001	0.918	0.908	1.000	0.859	0.895	0.999
0.2	0.6	5:1	0.028	0.103	0.001	0.110	0.111	0.001	0.922	0.897	0.999	0.892	0.889	0.999
0.2	0.6	10:1	0.030	0.102	0.000	0.106	0.107	0.000	0.914	0.898	1.000	0.902	0.893	1.000
0.2	0.2	1:1	0.018	0.071	0.001	0.114	0.076	0.001	0.858	0.929	0.999	0.786	0.924	0.999
0.2	0.2	2:1	0.020	0.085	0.000	0.108	0.091	0.000	0.868	0.915	1.000	0.840	0.909	1.000
0.2	0.2	5:1	0.028	0.092	0.000	0.110	0.098	0.000	0.871	0.908	1.000	0.876	0.902	1.000
0.2	0.2	10:1	0.030	0.093	0.000	0.106	0.095	0.000	0.861	0.907	1.000	0.891	0.905	1.000

Note: $\lambda_3 = \lambda_1$ in all experiments.

Table 6: Results of the panel logit random effects model estimation, marginal effects, 5 minute sampling frequency

	Joint jump days			Conflicting jump days		
	Maturity pairs	Term structure		Maturity pairs	Term structure	
	spot and futures	spot	futures	spot and futures	spot	futures
$News$	-0.015	0.022**	-0.015***	0.027**	0.053*	0.018**
	(0.013)	(0.010)	(0.009)	(0.012)	(0.005)	(0.008)
D_{Mo}	0.059***	0.056*	0.066*	-0.008	-0.034*	0.014
	(0.031)	(0.017)	(0.016)	(0.009)	(0.005)	(0.014)
D_{Tue}	0.008	-0.013	0.011	-0.021**	-0.024*	0.006
	(0.017)	(0.015)	(0.014)	(0.011)	(0.005)	(0.013)
D_{Wed}	-0.003	-0.038*	0.027***	-0.006	-0.025*	0.023***
	(0.016)	(0.014)	(0.014)	(0.009)	(0.005)	(0.014)
D_{Thu}	-0.026	-0.011	-0.008	-0.033**	-0.036*	-0.019
	(0.019)	(0.015)	(0.014)	(0.014)	(0.004)	(0.012)
$Expiry_{10,30}$	0.065	-	0.004	0.034	-	0.025
	(0.073)	-	(0.039)	(0.029)	-	(0.037)
$Expiry_{2,5}$	-0.006	-	0.041	-	-	-0.046
	(0.047)	-	(0.045)	-	-	(0.034)
M_2	-	0.178*	0.208*	-	-0.064*	-0.036*
	-	(0.017)	(0.011)	-	(0.006)	(0.010)
M_5	-	0.035**	0.105*	-	-0.027*	-0.026*
	-	(0.017)	(0.010)	-	(0.006)	(0.010)
M_{10}	-	0.017	0.024**	-	-0.008	0.009
	-	(0.016)	(0.010)	-	(0.005)	(0.010)

Note: ***, ** and * indicate statistical significance at 10%, 5% and 1%. Standard errors are in parentheses. $Exp_{2,5}$, is excluded from the conflicting maturity pairs due to no conflicting days on expiry dates for these maturities.

Table 7: Results of the panel logit random effects model estimation, 8 individual surprises, marginal effects, 5 minute sampling frequency

	Joint jump days			Conflicting jump days		
	Maturity pairs	Term structure		Maturity pairs	Term structure	
	spot&futures	spot	futures	spot&futures	spot	futures
$News$	-0.017	0.024**	-0.016***	0.022**	0.041*	0.013
	(0.013)	(0.010)	(0.009)	(0.010)	(0.005)	(0.009)
$US\ NAPM$	0.012	-0.023	-0.004	0.009	0.023*	0.012
	(0.021)	(0.025)	(0.019)	(0.010)	(0.005)	(0.015)
$Industrial\ Production$	0.031	-0.035	0.001	-0.003	0.000	-0.018
	(0.025)	(0.037)	(0.020)	(0.016)	(0.009)	(0.027)
$Capacity\ Utilisation$	-0.013	-0.002	0.015	0.005	0.006	0.024
	(0.026)	(0.024)	(0.021)	(0.014)	(0.008)	(0.021)
PPI	-0.017	0.017	-0.011	-0.012	-0.004	-0.015
	(0.025)	(0.021)	(0.020)	(0.014)	(0.008)	(0.020)
CPI	-0.033	-0.041***	-0.015	-0.026	-0.037*	-0.009
	(0.029)	(0.023)	(0.020)	(0.017)	(0.009)	(0.019)
$Retail\ Sales$	0.032	0.086*	0.023	0.003	0.011	-0.024
	(0.028)	(0.021)	(0.019)	(0.013)	(0.008)	(0.020)
GDP	-0.057***	-0.080*	-0.012	-0.007	-0.022*	0.064*
	(0.035)	(0.021)	(0.020)	(0.013)	(0.007)	(0.020)
$Non-farm\ pos$	0.050	-0.218*	-0.027	0.062**	0.084*	0.139*
	(0.047)	(0.076)	(0.042)	(0.028)	(0.011)	(0.027)
$Non-farm\ neg$	0.000	-0.050***	0.025	0.061*	0.072*	0.055*
	(0.029)	(0.029)	(0.022)	(0.025)	(0.008)	(0.018)
$Surp\_other$	-0.003	-0.004	-0.004	-0.002	-0.004***	0.007
	(0.006)	(0.006)	(0.005)	(0.003)	(0.002)	(0.005)
D_{mo}	0.066***	0.048*	0.070*	0.009	-0.016*	0.031**
	(0.034)	(0.017)	(0.017)	(0.011)	(0.006)	(0.016)
D_{Tue}	0.014	-0.022	0.015	-0.004	0.002	0.025***
	(0.019)	(0.015)	(0.015)	(0.010)	(0.007)	(0.015)
D_{Wed}	0.004	-0.044*	0.031**	0.012	-0.002	0.040*
	(0.017)	(0.014)	(0.015)	(0.011)	(0.007)	(0.015)
D_{Thu}	-0.019	-0.020	-0.004	-0.017	-0.014**	-0.002
	(0.018)	(0.015)	(0.014)	(0.011)	(0.006)	(0.014)
$Expiry_{10,30}$	0.068	-	0.005	0.040	-	0.032
	(0.074)	-	(0.039)	(0.031)	-	(0.038)
$Expiry_{2,5}$	-0.005	-	0.042	-	-	-0.050
	(0.047)	-	(0.045)	-	-	(0.033)
M_2	-	0.178*	0.208*	-	-0.065*	-0.036*
	-	(0.017)	(0.011)	-	(0.006)	(0.010)
M_5	-	0.035**	0.105*	-	-0.028*	-0.026*
	-	(0.017)	(0.010)	-	(0.005)	(0.010)
M_{10}	-	0.017	0.024**	-	-0.008	0.009
	-	(0.016)	(0.010)	-	(0.005)	(0.010)

Note: ***, ** and * indicate statistical significance at 10%, 5% and 1%. Standard errors are in parentheses. $Exp_{2,5}$, is excluded from the conflicting maturity pairs due to no conflicting days on expiry dates for these maturities. $Surp\_other$, $Non-farm\ pos$ and $Non-farm\ neg$ represent standardized surprises from: news releases other than eight news included in the regression, positive non-farm payrolls and negative non-farm payrolls.

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