Option Implied Information – Observing the Emotional State of the Market

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14.04.2015

I would like to thank Thomas Dangl (TU Vienna) for his support and numerous stimulating discussions.

Option Implied Information

- Asset pricing
  - Wide area of research
  - Concerned with the determination of a fair price of securities
  - Uses historic market prices and probabilities for future scenarios
  - Classic examples – Black Scholes option pricing formula, pricing of exotic derivatives

$$C = S_0 N(d_+) - K e^{-rT} N(d_-)$$

Option Implied Information

- Option Implied information
  - Reverses the approach
  - Uses observed prices and deducts expectations of the market
  - Allows further insight in the current state of the market
  - $\hat{f}_{(S_T)}$ implied Risk Neutral Density function

$$C = \int_K^\infty e^{-rT}(S_T - K)\hat{f}_{(S_T)}\, dS_T$$

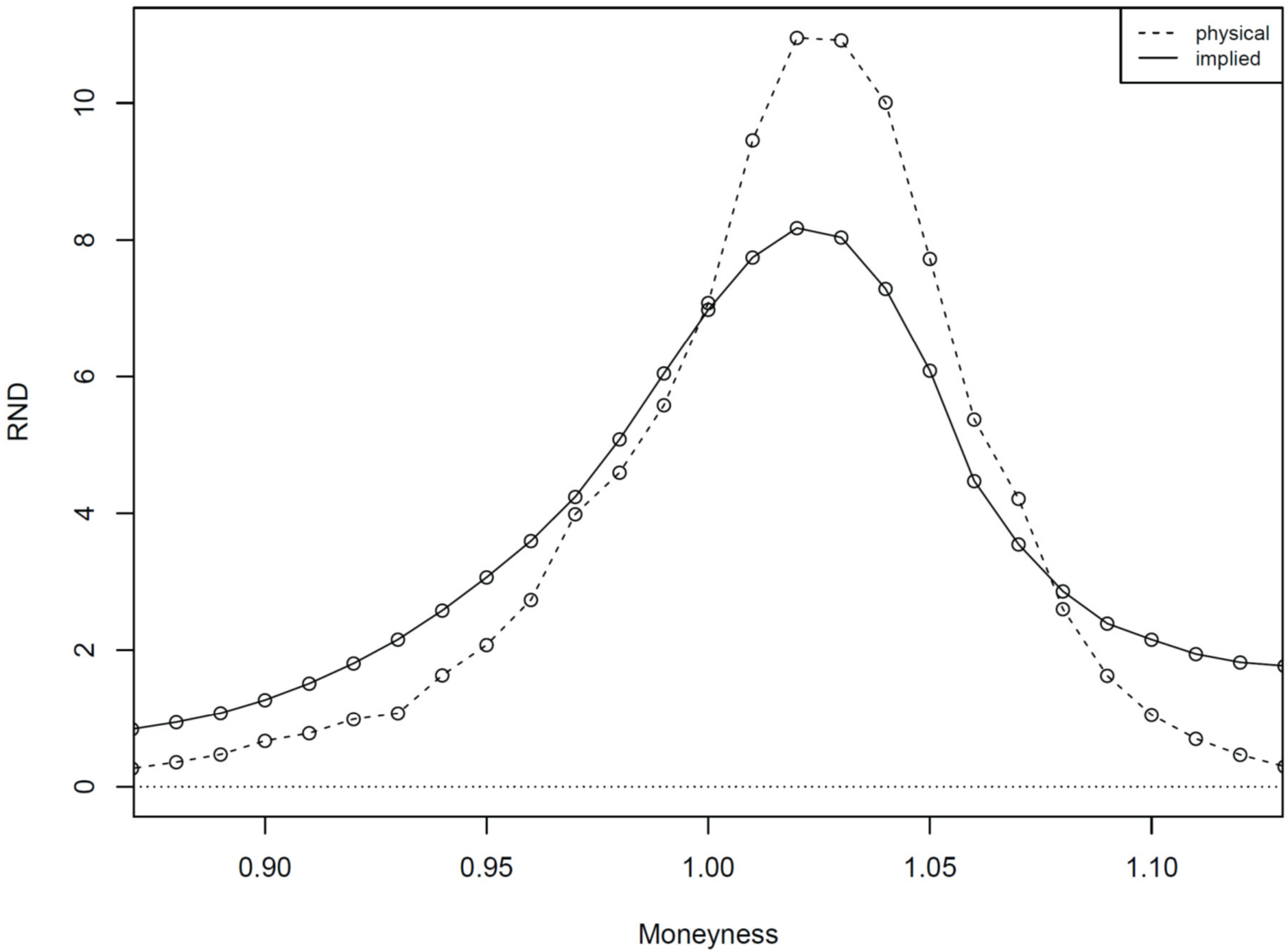


Figure 8: Physical probability density vs. implied RND, 1996-2013.

RND extraction

- Starting from:

$$C = \int_K^\infty e^{-rT}(S_T - K)\,\hat{f}_{(S_T)}\;dS_T$$

- Differentiation yields:

$$\frac{\partial C}{\partial K} = -\int_K^\infty e^{-rT}\hat{f}_{(S_T)}\;dS_T$$

$$\hat{f}_{(S_T)} = e^{rT}\frac{\partial^2 C}{\partial K^2}$$

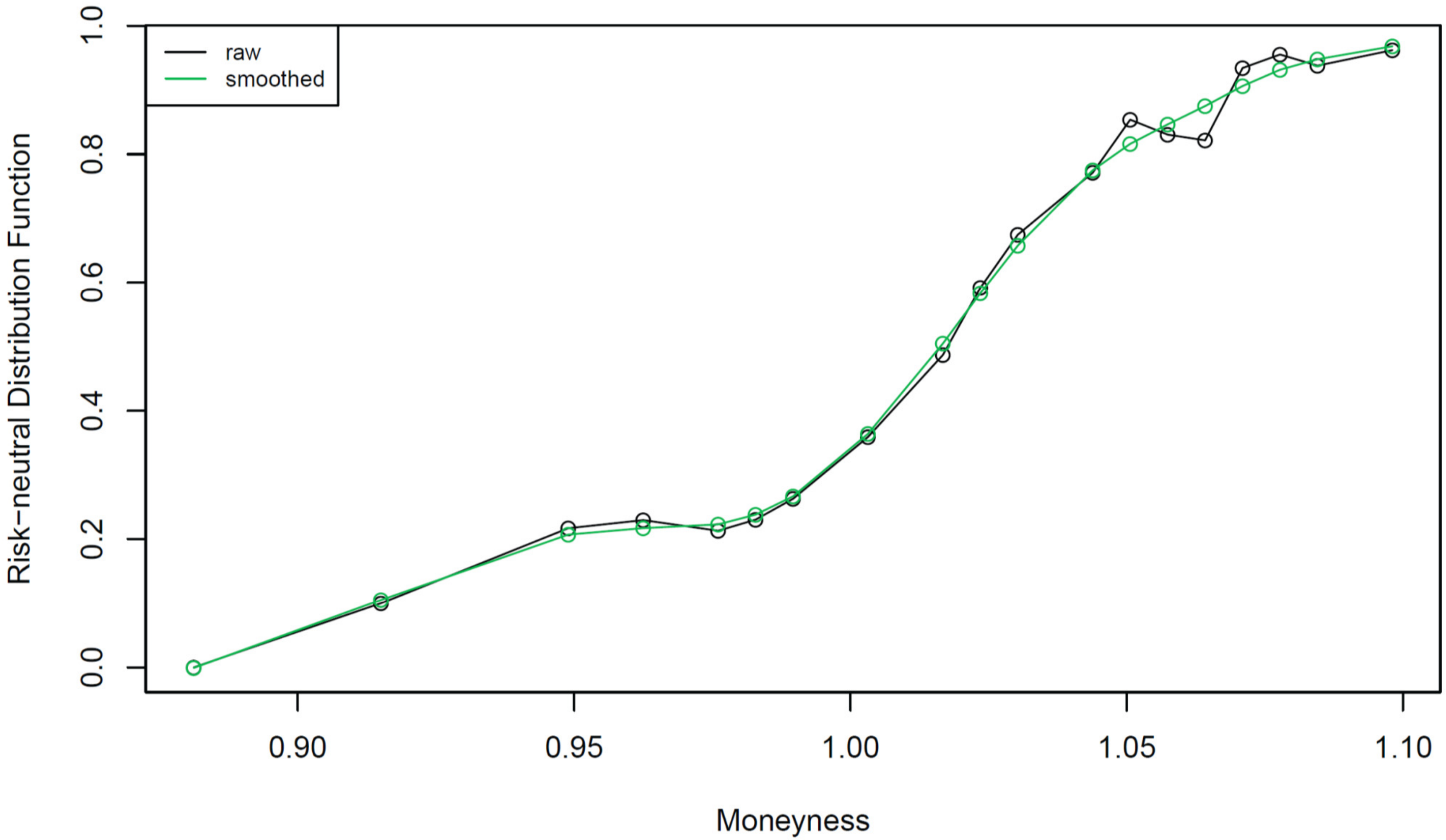
- Numerical derivatives for estimation (Breeden and Litzenberger 1978, Figlewski 2008)

RND extraction

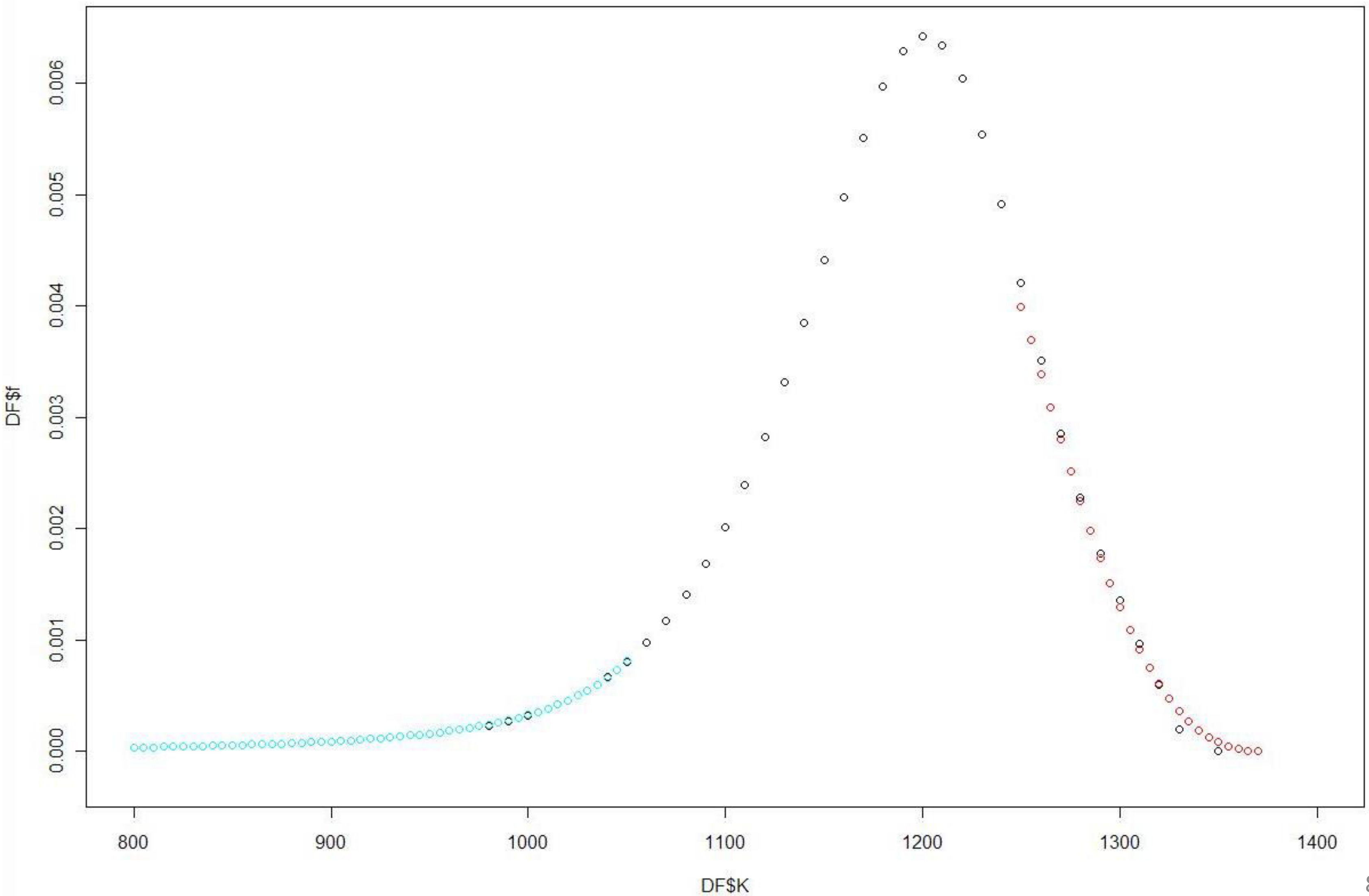
- Dense set of option prices required
- Convert option prices into Black-Scholes implied volatilities (Shimko 1993), smooth and interpolate, and reconvert back to prices
- Use B-splines to smooth and interpolate (robust to using polynomials, third or fourth-order splines etc., or kernel)
- Estimate the RND and risk-neutral distribution function using numerical derivatives
- Fit tails of distributions with generalized extreme value distribution (alternative approaches: sums of normal and beta distributions)

$$F(z) = e^{\left(-(1+\xi z)^{-\frac{1}{\xi}}\right)}, \qquad z = \frac{S_T - \mu}{\sigma}$$

Smoothing


raw
smoothed
Risk−neutral Distribution Function
0.0
0.2
0.4
0.6
0.8
1.0
0.90
0.95
1.00
1.05
1.10
Moneyness

Tail-Fit of RNDs



Contributions to the Literature

- **Smooth Ambiguity Aversion: A Tale of Two Risks**
  (M. Puhl, P. Savor - Fox School of Business, M. Wilson – SBS, Oxford University)
  - Risk Aversion of Representative Agent from OI-Information
  - Anomalies around Economic Announcements
  - Evidence for Ambiguity Risk Premium
- **Predicting Liquidity Crises with Option-Implied Information**
  - Liquidity and Liquidity Crises Prediction
  - Model based on Option Implied Information (OI-I)
- **Option-Implied Information and the Cross-Country Propagation of Liquidity**
  - International Liquidity Propagation
  - Quantification and Prediction with Option Implied Information

Smooth Ambiguity Aversion: A Tale of Two Risks

(M. Puhl, P. Savor - Fox School of Business,
M. Wilson – SBS, Oxford University)

14.04.2015

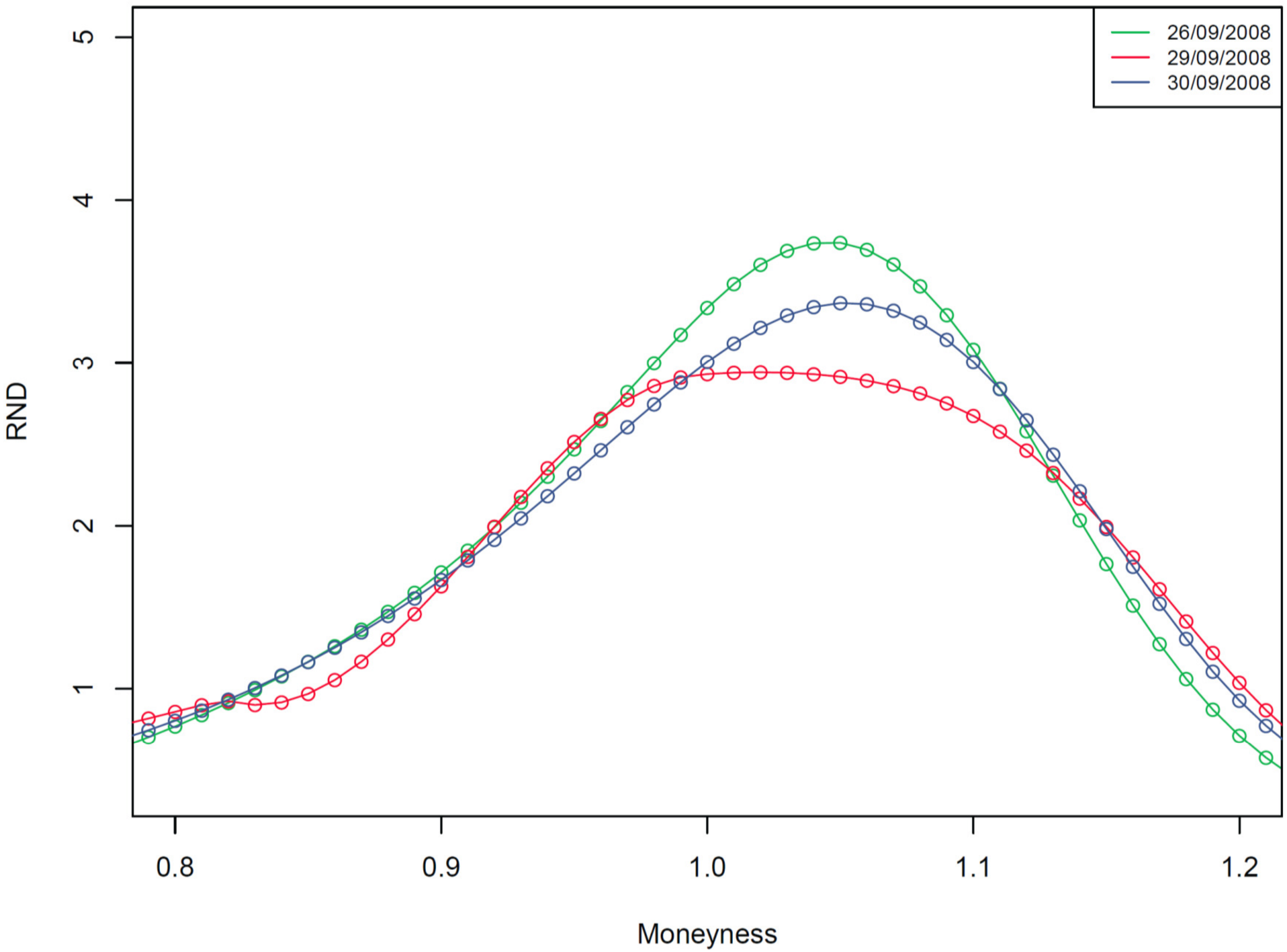


Figure 7: Risk-neutral probability density (RND) before, on, and after September 29, 2008.

Risk vs. Uncertainty

- Knight (1921)
  - You not only do not know what will happen, but you do not known the probabilities associated with various potential outcomes
- Ellsberg paradox (1961): in experiments people reveal overwhelming preference for lotteries with known distribution of payoffs, over those with the same expected value but uncertainty about the distribution from which they are drawn
- **Ambiguity aversion** can rationalize this: people are averse to uncertainty as well as risk
- But hardly any direct evidence on its effect on asset prices

Ambiguity Aversion

- Considering ambiguity aversion in a generic model of preferences

$$V = \max_{\alpha} E\left[f(\widetilde{Y};\alpha,\widetilde{\theta})\right]$$

- Assuming the investors can rebalance the portfolio frequently, effect of smooth ambiguity aversion on welfare becomes $o(\Delta t^2)$, i.e. negligible.
- If that is not possible, e.g. before an announcement, ambiguity aversion should be significant (first-order $o(\Delta t)$)
- No other representative agent model predicts this
- Quantifiable with concavity of representative agent's utility function. (Breeden and Litzenberger (1978), Ait-Sahalia and Lo (2000), Gollier (2011))

Implied Concavity Index (CI)

$$CI(s) = -\frac{W_s \frac{d}{dW} \lambda(W_s)}{\lambda(W_s)} \qquad \lambda(W_s) = \pi_s / p_s$$

$$CI(W_s) = \gamma(W_s) - W_s \frac{d}{dW_s} \ln\left(\frac{\hat{f}(W_s)}{f(W_s)} \right)$$

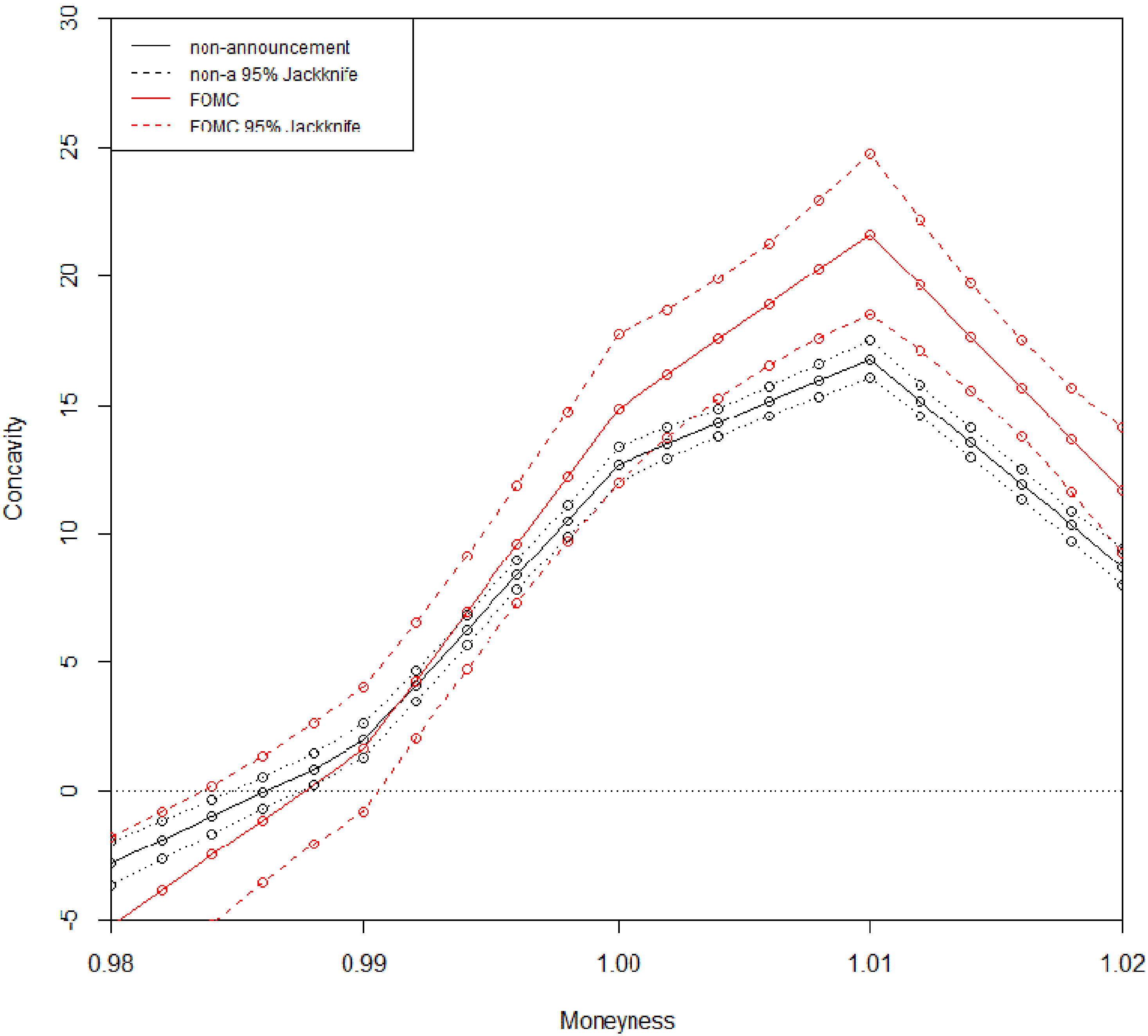
- The first term is just relative risk aversion, while the second term depends on the distortion induced to state probabilities by ambiguity aversion.
- We show in the paper that the second term is of second order for non-announcement periods, but of first-order for announcement periods in the presence of ambiguity aversion
- **Implication**: increase in *CI* around announcements represents evidence for the existence of an ambiguity premium

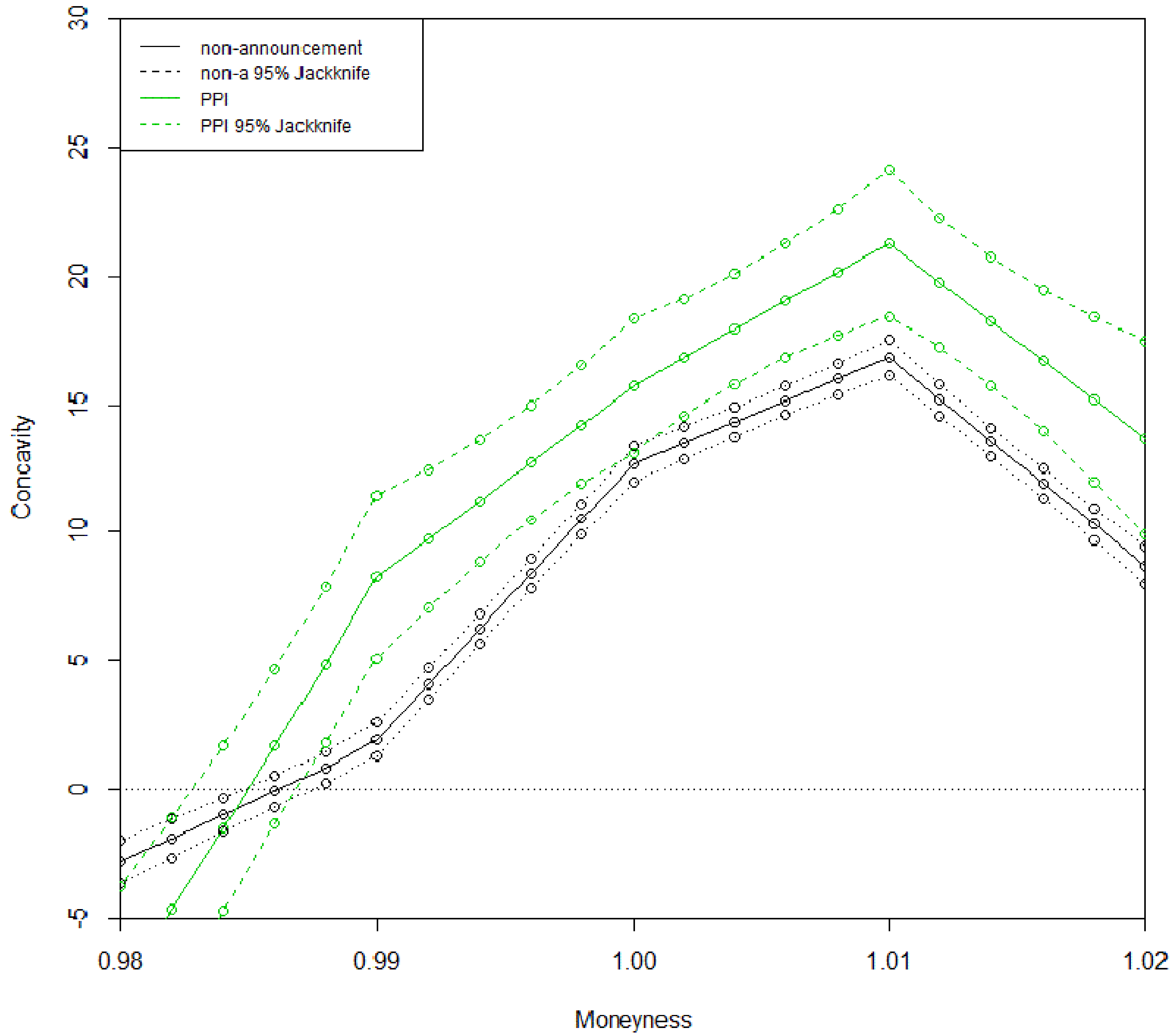
Table 2

Concavity Index

This table presents the mean and standard deviation of the concavity index on announcement and non-announcement days. The announcement days include days when the FOMC is releasing its decision (FOMC), when PPI numbers are released (PPI), and when employment numbers are released (Emp). The last three columns show p-values of a t-test, Kolmogorov-Smirnov (KS) test, and Mann-Whitney (MW) test for the difference between announcement and non-announcement days.

Type	Mean	Std. Dev	t-test	KS	MW
Non-Ann.	8.3	7.5	-	-	-
FOMC	9.7	6.7	4.1%	5.0%	5.7%
PPI	9.7	7.7	2.5%	11.5%	5.4%
Emp	8.6	7.5	31.9%	39.6%	35.6%
All Ann.	8.9	7.1	4.1%	19.6%	6.3%


non-announcement
non-a 95% Jackknife
FOMC
FOMC 95% Jackknife
Concavity
30
25
20
15
10
5
0
-5
0.98
0.99
1.00
1.01
1.02
Moneyness



non-announcement
non-a 95% Jackknife
PPI
PPI 95% Jackknife
Concavity
Moneyness
-5
0
5
10
15
20
25
30
0.98
0.99
1.00
1.01
1.02

Summary of main findings

- Implied concavity of preferences increases ahead of Federal Open Markets Committee (**FOMC**) and inflation (Producers Price Index (**PPI**) announcements
- Concavity increases from 8.3 in normal times to between 10.4 and 11.6 ahead of announcements (p-value max 0.3%)
- Strong evidence for the existence of an ambiguity risk premium

Predicting Liquidity Crises with Option-Implied Information

14.04.2015

Measurement of Liquidity

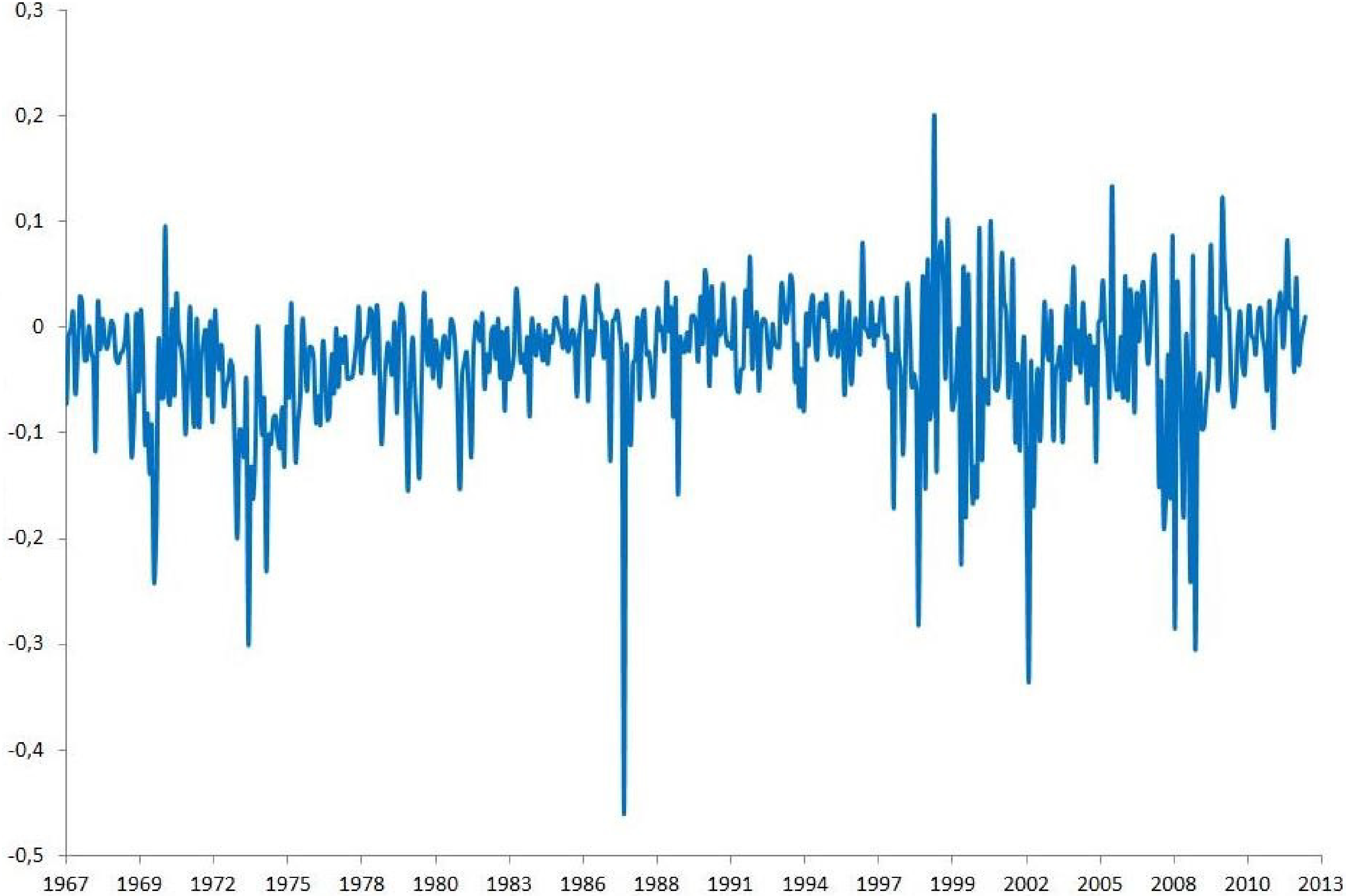
- Different benchmarks for the measurement of liquidity:
  - Impact of order volume on price (e.g. Pástor and Stambaugh, Amihud)
  - Effective and realized spread (Roll, Effective Tick, Holden)
- **Pástor and Stambaugh's aggregated liquidity** γ is used:

$$R^e_{i,d} = \vartheta_i + \Phi_i * R_{i,d-1} + \gamma_i * sign(R^e_{i,d-1}) * V_{i,d-1} + e_{i,d}$$

  - The liquidity measure $\gamma_{i,t}$ is defined as the volume sensitivity regressed over one month. (monthly measure, return $R_{i,d}$, volume $V_{i,d}$)
- **Amihud's Illiquidity**:

$$Illiq_t = \emptyset\left(\frac{|r_{t,i}|}{volume_{t,i}}\right)$$

Pástor and Stambaugh – Aggregated Liquidity



Methodology

- Characteristics of RND, prediction for next months' liquidity
  - Moments of the distribution (M1-M5), incl. kurtosis and skewness
  - Volatility difference – difference between put and call volatility at the max of the RND
  - Implied volatility at the max of the RND
- Multivariate regression (in-Sample)
- Strict out-of-sample test

$$R^2 = 1 - \frac{\sum(y - \hat{y})^2}{var(y)(n-1)}$$

  - Sliding time windows of 72 months
  - Stability Comparison with naive models (mean reversion, last value)

Results – Multivariate Regression

In-sample:

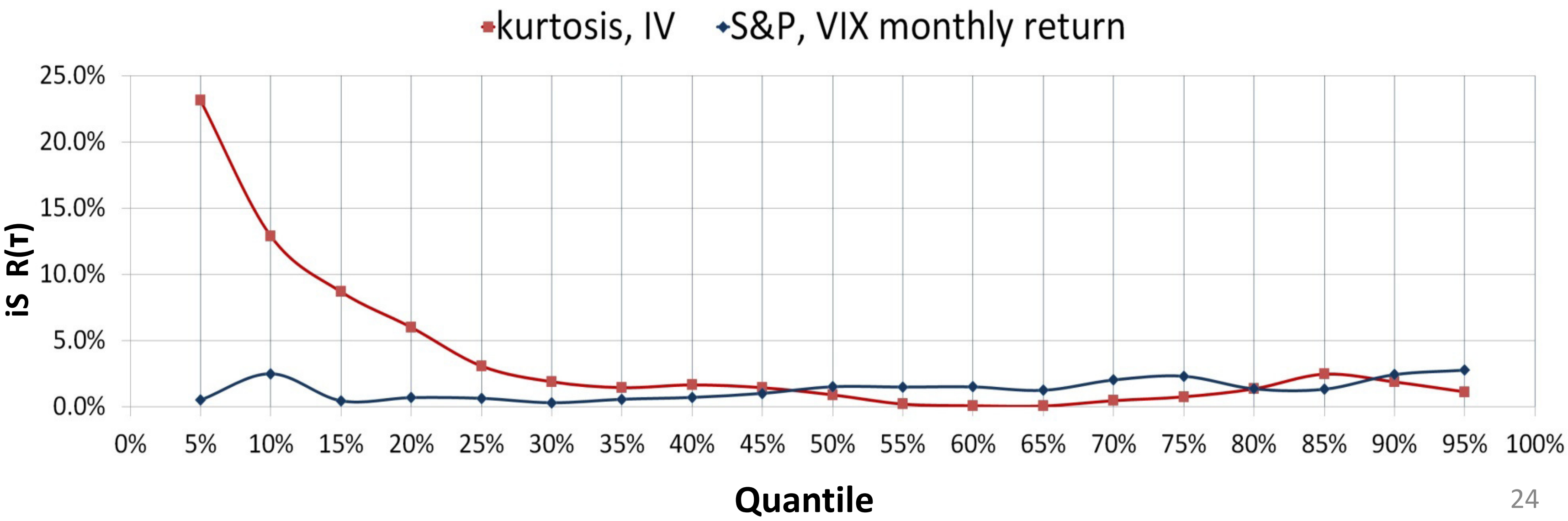
- Kurtosis and implied volatility
- R^2 8.5% (adjR^2 6.9%), t-test p-values of 8.1%

Out-of-sample:

- Second moment M2, and the Put/Call volatility difference
- R^2 6.2%, avg. F-statistic p-value: 10.1%
- Stability tests passed (Naïve Models, VIX comparison)

Results - Quantile Regression

- The RND implied model is in particular better suited to describe low liquidity quantiles, i.e. liquidity crises.
  - S&P, VIX: $iS\ R_{(\tau)}{}^{1}$ 0-3%
  - Kurtosis, implied vola: iS $R_{(\tau)}{}^{1}$ 0-23.1%, OOS: 0-19.4%
- Use as warning indicator for imminent liquidity crisis
- Market timing signal in asset management.



Option-Implied Information and the Cross-Country Propagation of Liquidity

Methodology

- Characteristics of RND, next weeks' liquidity:
  - Moments of the distribution (M1-M5), incl. kurtosis and skewness, Put/Call difference, implied vola
  - Macroeconomic and financial factors (gold, brent oil, equity indices, liquidity measures, interest rate spreads:
- 5 Countries: S&P 500, Dax 30, FTSE 100, Eurostoxx 50, Nikkei 225
- Time series: Jan 2010 to May 2014
- In-country analysis
- Cross-Country Analysis
- Analysis of contributing factors

Results – Multivariate Regression

- Significant explanatory and predictive power over all five geographies.
- High in-sample and out-of-sample R^2 values at significant t- and F-statistic levels (F-pval around 0.1%)
  - US: 43%, DE: 14%, EU: 7%, UK: 5%, JP: 14%
- Consistent behaviour of explanatory variables over geographies.
- Stability test vs. BS-implied volatility and naïve models passed
- Contribution analysis: Option Implied Information substantially adds predictive power.

Table 2
Contribution to Predictive Power – Amihud/local

Country		Full	OI-only	Macro	Momentum	Index	IV
USA	OOS R^2	43.0 %	28.7 %	4.8%	17.5 %	40.3 %	6.9 %
	iS R^2	49.1 %	31.7 %	18.9 %	15.24 %	45.1%	10.7%
	F-pval	0 %	0 %	0 %	0 %	0 %	0 %
GE	OOS R^2	14.2 %	7.4 %	0.9 %	0 %	0 %	0 %
	iS R^2	10.1 %	7.5 %	1.2 %	0.8 %	2 %	0 %
	F-pval	0 %	0.3%	11.5%	17.6 %	9.8%	96.0 %
EU	OOS R^2	6.6 %	1.5 %	3.2 %	2.0 %	0 %	0 %
	iS R^2	8.6 %	5.0 %	1.5 %	2.3 %	0.8 %	0.1 %
	F-pval	0.1 %	0.5 %	7.9 %	3.0 %	18.9%	59.8 %
UK	OOS R^2	6.8 %	6.8 %	0 %	0 %	0 %	0 %
	iS R^2	4.2 %	4.2 %	3.1 %	0 %	0.2 %	0 %
	F-pval	3.4 %	3.4 %	7.9 %	80.0 %	53.4 %	74.2 %
JP	OOS R^2	14.0 %	1.8 %	0 %	1.8 %	10.4 %	0 %
	iS R^2	20.7 %	7.5 %	1.3 %	3.6 %	13.4 %	4.4 %
	F-pval	0 %	0 %	9.9 %	0.5 %	0 %	0.2 %

Results – Multivariate Regression, Cross-Country

- Significant explanatory power between connected economies.
- Extent of the cross-country explanatory power a **quantification of the dependencies between those economies** and offers insight in the propagation of market liquidity between them.
  - High interconnection between the USA and Europe. Especially market liquidity in the UK shows the highest dependency on US conditions.
  - Weaker, but still significant linkage between Japan and the US as well as Europe
  - Surprisingly low impact of US on Europe – Central Bank driven markets

Applications:

- **warning indicator** – also considering cross country propagation of liquidity and liquidity crises.
- **valuable market timing instrument** avoidance of liquidity crises and more efficient harvesting of liquidity premia.

Table 3
International Cross Influence – Amihud

		USA	GE	EU	UK	JP
USA	OOS R^2	43.0 %	25.2 %	23.8 %	28.1 %	11.5 %
	iS R^2	49.1 %	32.4 %	33.2 %	35.9 %	14.8 %
	F-pval	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
GE	OOS R^2	7.8 %	14.2 %	11.7 %	20.3 %	6.1 %
	iS R^2	11.4 %	10.1%	7.5 %	9.8 %	6.6 %
	F-pval	0.1 %	0.1 %	0.1 %	0.1 %	0.6 %
EU	OOS R^2	5.8 %	7.3 %	6.6 %	5.3 %	8.5 %
	iS R^2	6.6 %	6.2 %	8.6 %	6.9 %	10.0 %
	F-pval	0.6 %	0.1 %	0.1 %	0.1 %	0.0 %
UK	OOS R^2	7.5 %	4.3 %	5.0 %	5.4 %	3.3 %
	iS R^2	3.3 %	1.5 %	9.3 %	4.1 %	4.8 %
	F-pval	10.1 %	20.2 %	0.1 %	3.0 %	6.6 %
JP	OOS R^2	5.7 %	1.1 %	2.0 %	5.3 %	14.0 %
	iS R^2	8.2 %	1.6 %	9.1 %	7.4 %	20.7 %
	F-pval	0.8 %	19.4 %	0.2 %	0.6 %	0.0 %

Conclusion

- Option-Implied information offers valuable insights in the expectations and characteristics of market participants.
- Allows estimate of risk aversion of representative agents
- Quantifies risk premia offered by the market
- Can be used to proof or refute theories in financial economics
- Contains predictive value
  - Warning indicators
  - Portfolio management
- Quantifies the interconnectedness of markets
- Valuable tool for researchers and practitioners.

Appendix

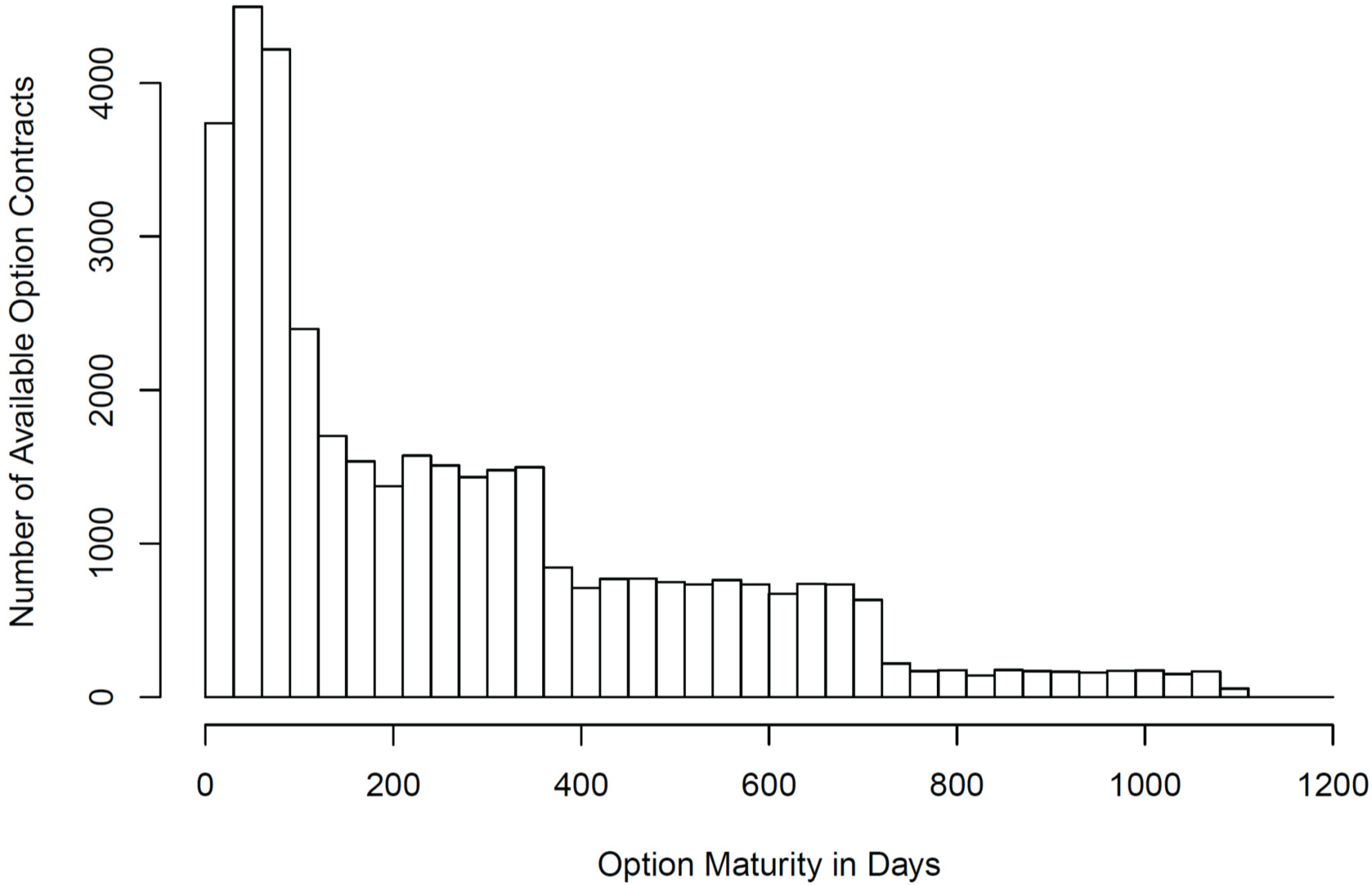


Figure 2: Data availability over option maturity.

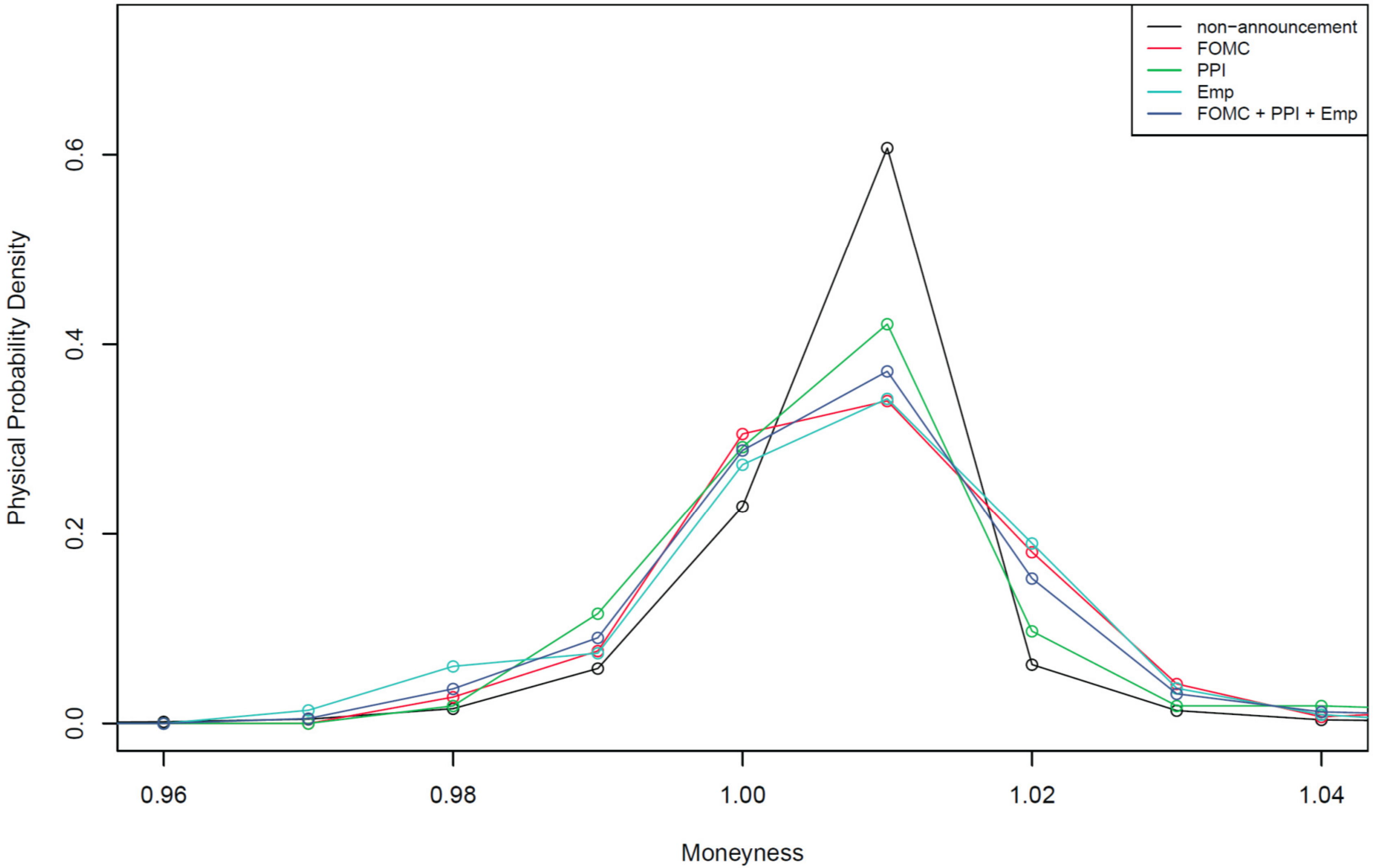


Figure 6: Physical probability density of S&P 500 returns over a 1-day horizon, 1996-2013.

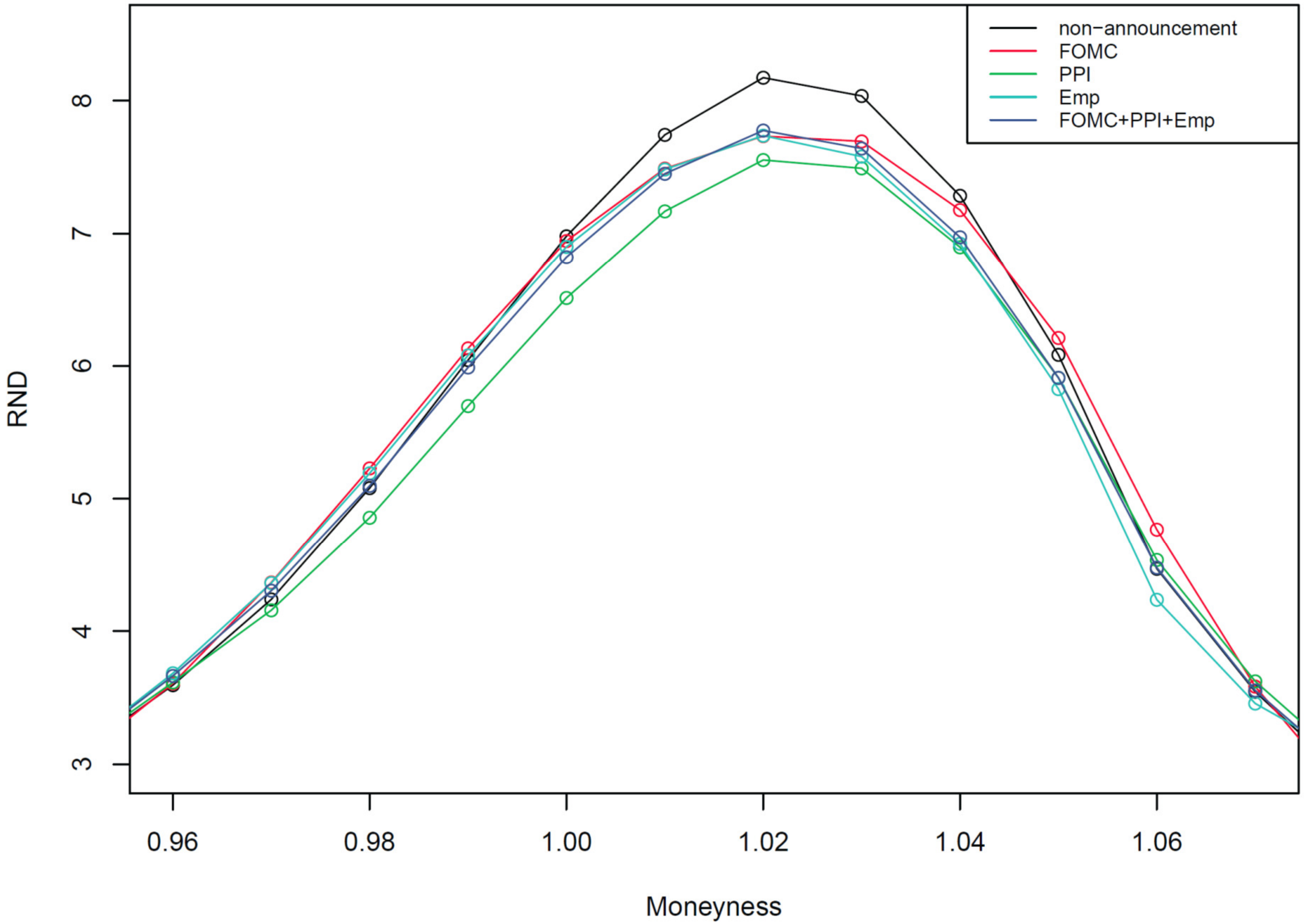


Figure 9: Implied risk-neutral probability densities (RND) for different types of days, 1996-2013.

Results – Multivariate Regression – Local

Table 1
Linear Regression - Amihud/local

Panel A: USA - S&P 500

OOS R^2	43.0 %		M2	M4	Implied Vola	Vola Diff.	S&P 500
iS R^2	49.1 %	β	3.7	-1.2	-4.5	-4.5	-4.5
F-pval	0%	(t-stat)	(1.99)	(-2.32)	(-3.06)	(-1.91)	(-9.26)

Panel B: Germany - DAX 30

OOS R^2	14.2 %		M2	M3	M4	Implied Vola	10-1yr spread
iS R^2	10.1 %	β	2.2	-2.6	-5.6	-1.4	-1.5
F-pval	0 %	(t-stat)	(4.03)	(-1.50)	(-2.07)	(-3.50)	(-2.44)

Panel E: EU - Eurostoxx 50

OOS R^2	6.6 %		M2	Vola Diff.	SX5E Amihud	BBB-AAA
iS R^2	8.6 %	β	8.9	-2.8	8.0	-1.1
F-pval	0.1 %	(t-stat)	(2.51)	(-1.65)	(2.21)	(-1.79)

Results – Multivariate Regression – Local

Table 1 (continued)
Linear Regression - Amihud/local

Panel C: UK - FTSE 100

OOS R^2	5.4 %		M2	M3	Vola Diff.
iS R^2	4.1 %	β	7.2	-1.8	-3.0
F-pval	3.0 %	(t-stat)	(2.70)	(-1.87)	(-1.56)

Panel D: Japan - Nikkei 225

OOS R^2	14.0 %		M4	Implied Vola	Vola Diff.	Nikkei	Nikkei Amihud
iS R^2	20.7 %	β	-3.5	-3.1	-4.6	-6.2	2.0
F-pval	0 %	(t-stat)	(-1.57)	(-1.68)	(-2.13)	(-5.61)	(3.10)

Table 4
Contribution to Predictive Power – Amihud/International

		GE	OI-only	non-OI
	OOS R^2	25.2 %	17.8 %	20.3 %
USA	iS R^2	32.4 %	16.0 %	30.0 %
	F-pval	0.0 %	0.0 %	0.0 %
		USA	OI-only	non-OI
	OOS R^2	7.8 %	2.1 %	3.4 %
GE	iS R^2	11.4 %	1.9 %	6.2 %
	F-pval	0.1 %	31.4 %	0.3 %
		USA	OI-only	non-OI
	OOS R^2	5.8 %	3.5 %	3.3 %
EU	iS R^2	6.6 %	5.8 %	5.4 %
	F-pval	0.6 %	0.4 %	1.7 %
		USA	OI-only	non-OI
	OOS R^2	7.5 %	7.5 %	4.5 %
UK	iS R^2	3.3 %	3.3 %	2.3 %
	F-pval	10.1 %	10.1 %	12.3 %
		USA	OI-only	non-OI
	OOS R^2	5.7 %	5.2 %	0.5 %
JP	iS R^2	8.2 %	7.9 %	0.6 %
	F-pval	0.8 %	0.5 %	31.3 %