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Volatility term structures in commodity markets

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Abstract

In this study, we comprehensively examine the volatility term structures in commodity markets. We model state-dependent spillovers in principal components (PCs) of the volatility term structures of different commodities, as well as that of the equity market. We detect strong economic links and a substantial interconnectedness of the volatility term structures of commodities. Accounting for intra-commodity-market spillovers significantly improves out-of-sample forecasts of the components of the volatility term structure. Spillovers following macroeconomic news announcements account for a large proportion of this forecast power. There thus seems to be substantial information transmission between different commodity markets.

KEYWORDS

commodities, information transmission, spillovers, volatility term structure

JEL CLASSIFICATION

G10; G14; G17

1 | INTRODUCTION

A large set of external events and conditions has the potential to affect commodity markets. Important drivers of commodity prices are, inter alia, weather, investor flows, and macroeconomic conditions. While the level of commodity prices is certainly important, understanding the volatility of commodity prices is at least as crucial. For example, Pindyck (2004) shows that, because storage helps to smooth production and deliveries, the marginal value of storage increases with volatility. Further applications where volatility is of special concern include risk management decisions, margin calculations, or the valuation of options contracts. While previous studies have examined the impact of commodity spot volatility, the entire volatility term structure provides additional important information for the above mentioned issues, since short-term and long-term options embed partly differential information and provide market expectations of future volatility over various horizons.

The importance of considering the entire term structure has been widely documented for equity markets (e.g., Adrian & Rosenberg, 2008; Bakshi, Panayotov, & Skoulakis, 2011; Feunou, Fontaine, Taamouti, & Tédongap, 2013). In particular, these studies show that the volatility term structure is informative about, inter alia, risk premia, measures of real economic activity, business cycle risk, and the tightness of financial constraints. Investigating the interconnectedness of the term structure and its relation with macroeconomic variables and announcements can be crucial to help understand the interdependencies and macroeconomic links of the commodity markets. This can be particularly helpful for practitioners that can use predictability of the entire volatility term structure for more accurate risk evaluations of their portfolios.

Our main contribution is to provide a comprehensive study of the volatility term structure of different commodity markets. The volatility term structure is of special interest for commodity markets because of its relation with the so called Samuelson (1965) effect. This effect states that volatility generally decreases with increasing time to maturity. In appreciating this, we can enhance our understanding of the determinants and dynamics of the volatility term structure.

First, we decompose the volatility term structure into its principal components (PCs) and study their economic drivers. We focus on the first three PCs: the level, the slope and the curvature of the term structure. This analysis allows us to understand how volatility dynamics change for contracts with different expiry dates.

When we investigate the macroeconomic determinants of the commodity volatility term structure, we uncover two main results. (a) Macroeconomic variables can explain a large proportion of the variation in the level factor, and typically a somewhat smaller share for the slope and curvature factors. (b) An increase in the proportion of speculative open interest reduces the volatility level for various markets, while employment is positively related to the volatility level.

Second, we use a state-dependent autoregressive (AR) model to examine volatility spillovers between commodity markets. We compare a model using only the past lags of one commodity volatility term structure to a state-dependent unrestricted AR-model which also includes the lagged volatility PCs of another commodity, following the causality model by Granger (1969, 1988). We define economic states based on the forecast of the Engle and Manganelli (2004) conditional autoregressive Value at Risk (CaViaR). Using the Granger (1969, 1988) causality model to make out-of-sample predictions of the implied volatility term structure generally yields sizable forecast improvements over the predictions of the simple state-dependent AR-model. Accounting for spillover effects for the level and the slope yields out-of-sample R^2s of up to 5%. Intra-commodity effects are more important for the commodity market than spillover effects originating from the equity market. Finally, spillovers are state-dependent: they are strongest during market distress and smallest during normal periods.

One possible explanation for these findings is information transmission. To isolate the effects originating from this channel, we investigate the impact of scheduled macroeconomic news announcements on spillovers. If spillovers are larger after macroeconomic news announcements, this would indicate that some commodity markets capture information on macroeconomic news earlier than others. This could lead to subsequent changes in the volatility term structure of cross-section of the commodity markets. We find that macroeconomic news announcements models do indeed explain up to 70% of the spillovers for the level. News announcements associated with consumer income or consumer sentiment have a particularly large influence on spillovers for all components of the term structure.

We also investigate the impact of the financialization of commodity markets, which leads to a stronger comovement across commodities in recent years due to the increased use of commodities as an investment (Christoffersen, Lunde, & Olesen, 2019; Tang & Xiong, 2012). We conduct a subsample analysis by studying changes in the lead/lag relationship between commodity markets pre- and post-financialization, which reveals two main findings: First, the volatility term structure for commodity and equity markets is strongly integrated for the post-financialization period. Second, there are two effects that affect spillovers postfinancialization: (a) the increase in contemporaneous movements lowers spillovers for the level and (b) more common factors for the slope and the curvature lead to overall higher spillovers.

Our study is related to several strands of the literature. For equity and bond markets a variety of articles show that the variance term structure is important and can capture unobserved risk factors. Adrian and Rosenberg (2008) and Bakshi et al. (2011) show that factors that describe the volatility term structure can predict various economic and financial measures. Bakshi et al. (2011) draw on an analogy with the term structure of interest rates and argue that the variance term structure embodies expected variances by both the financial and the real sector, as perceived by the index option market.[1]

For commodity markets, there is a vast literature that finds a factor structure in returns. Rotemberg and Pindyck (1990), Yang (2013), Szymanowska, De Roon, Nijman, and Van Den Goorbergh (2014), and Bakshi, Gao, and Rossi (2017) argue that common factors in commodity markets can explain a large proportion of cross-sectional return variation. For their analyses, these studies use the cross-section of commodity returns. Brunetti, Büyükşahin, and Harris (2016) show that hedge funds positions are negatively related to the volatility in corn, crude oil, and natural gas futures markets. Hammoudeh and Yuan (2008) investigate the effects of oil and interest rate shocks on the volatility of metals markets, using various GARCH model specifications.

Our study extends this literature by investigating the entire volatility term structure for a large cross-section of commodity markets. Leveraging the various expiration dates of commodity futures and options enables us to study the term structure and analyze whether there is a common factor structure in the volatility term structure.

[1]Further studies on the volatility term structure in equity markets include: Campa and Chang (1995), Mixon (2007), Johnson (2017), and Hollstein, Prokopczuk, and WeseSimen (2019).

The central contribution of our paper is the analysis of the lead/lag factor structure of commodity markets. Volatility spillovers of the commodity market have been investigated in several studies, but only in relation to specific markets and to the volatility of the spot market. Diebold and Yilmaz (2012) investigate volatility spillovers across different markets using a generalized vector autoregressive (VAR) framework. Du and He (2015) investigate Granger causality in risk between the returns of the crude oil market and stock market returns. They find that after the financial crisis the crude oil market was positively linked to the stock market, while it was negatively linked to the stock market beforehand. Nazlioglu, Erdem, and Soytas (2013) investigate spillovers in spot volatility between oil and agricultural markets. In the literature, spillovers are usually only investigated for certain events that trigger an increased dependency between the markets—for example, the food crisis. One reason for this might be that it is difficult to link spillovers to a particular cause. In this study, we examine macroeconomic news announcements for exactly this purpose.

In doing so, we add to the literature that uses macroeconomic news announcements to investigate the impact on returns or volatilities (Lucca & Moench, 2015; Savor & Wilson, 2013; Wachter & Zhu, 2018).

Finally, our study is related to the literature on financialization. Tang and Xiong (2012) investigate the correlation between crude oil returns and other commodities, and find that these correlations increase for a post-financialization period starting in 2004. Christoffersen et al. (2019) investigate returns and variances of commodities in the post-financialization period. They find that the factor structure is stronger for volatility, and that volatilities are strongly related to stock market volatility and the business cycle. We extend this literature by providing insights about the financialization of the entire commodity volatility term structure and are able to capture a more complete picture than the previous literature. The existing studies focus on contemporaneous movements, but not on the lead/lag relations in the commodity market. We are the first study to investigate the impact of financialization on the lead/lag structure of the commodity market volatility.

The remainder of this paper is organized as follows: In Section 2 we describe the data and methodology. In Section 3 we present our main analysis and in Section 4 we provide robustness tests. Section 5 concludes.

2 | DATA AND METHODOLOGY

2.1 | Volatility term structures in commodity markets

We obtain the commodity futures and options data set from the Commodity Research Bureau (CRB). Our data covers the period from January 1, 1996 until December 31, 2015. We consider the following commodities: cocoa, coffee, copper, corn, cotton, crude oil, gold, natural gas, silver, soybeans, and sugar. The selection of these commodities is based on the need for a sufficient range of options over a reasonably long time period. Because we want to study the impact of financialization on the lead/lag structure in the volatility term structure, we require that commodities have option data before 2000. We exclude a commodity for a certain year if the data coverage is below 70% of trading days.

We handle and filter the data set following Prokopczuk, Symeonidis, and WeseSimen (2017) and Hollstein, Prokopczuk, and Tharann (2019) and remove all options that are in-the-money, have a time to maturity of less than 1 week or have a price lower than five times the minimum tick size. As risk-free rate, we use the daily Treasury yield.[2] We further remove observations that violate standard no-arbitrage conditions, as in Aït-Sahalia and Duarte (2003). Each day, we need to observe at least two out-of-the-money call- and put-options, otherwise we remove this particular day from the sample. We follow Chang, Christoffersen, Jacobs, and Vainberg (2011) and Hollstein and Prokopczuk (2016) to interpolate the implied volatilities of options via cubic splines by moneyness $\left(\frac{K}{F}\right)$, where K is the strike price and F is the price of a future with the same maturity as the option. From this set of options we calculate option prices using the Black (1976) formula. We use a constant extrapolation for the moneyness levels above and below the daily maximum and minimum levels. As a result we obtain a fine grid of 1,000 implied volatilities between a moneyness of 1% and 300%. With this data set, we compute model–free implied volatilities. For the S&P 500, we use options data from OptionMetrics and apply the same procedure.

We compute model-free option-implied volatility for various maturities using the nonparametric approach of Demeterfi, Derman, Kamal, and Zou (1999) and Britten-Jones and Neuberger (2000) as:

[2]https://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=yield.

$$\mathrm{VIX}_t^2 = \frac{2R_t^f}{T-t}\left[\int_0^{F_{t,T}} \frac{1}{K^2}\mathrm{p}_{t,T}(K)dK + \int_{F_{t,T}}^{\infty} \frac{1}{K^2}\mathrm{c}_{t,T}(K)dK\right]. \tag{1}$$

R_t^f is the continuously compounded risk-free rate and $F_{t,T}$ is the futures price at date t for maturity T. $p_{t,T}$ the put price and $c_{t,T}$ is the call price with strike K of respective out-of-the-money options. For some commodities, volatility exhibits seasonality, which could have a mechanical impact on the term structure as well as on spillover effects. To remove seasonal effects, we use a trigonometric function, following Back, Prokopczuk, and Rudolf (2013):

$$k_i cos(\omega g_i(t, \tau) - \omega\theta_i), \tag{2}$$

where $\omega = \frac{2\pi}{12}$ is the cycle length and $g_i(t, \tau) = t + 12\tau - S_i\left[\frac{t + 12\tau}{S_i}\right]$. The operator $[X]$ returns the largest integer which is not greater than x. k_i is the specific exposure to the season, θ_i is the peak of the seasonal structure and τ is the contract maturity. We set S_i to 12 corresponding to monthly seasonality. $g_i(t, \tau)$ results, therefore, in integers from 0 to 11 representing the corresponding months. For each commodity, we regress the implied volatility on the mechanical model implied by Equation (2) and retain the residual series.

Table 1 shows the summary statistics of the volatility term structures. One can observe that the average volatility is decreasing with increasing maturity. This effect is strongest for non-metal commodities. For metals, the term structure is relatively flat. For the equity market, the volatility slightly increases with maturity. Thus the implied volatility term structure for commodity markets has unique features which makes it interesting to investigate. The standard deviation of the volatilities is lower for the annual maturities, except for gold, where the standard deviation is constant. The first autoregressive component is usually larger for longer-term volatilities, indicating a stronger persistence. This is not the case for energies, where long-term volatilities are less persistent.

2.2 | Macroeconomic data

We use a similar approach as Stock and Watson (2012) to investigate the macroeconomic determinants of the commodity volatility term structure. Specifically, we order various macroeconomic variables into groups and obtain the first PC of each macroeconomic group. In Table A1 of the Online Appendix, we describe the sources of our data set as well as the applied standardization technique. We obtain factors representing the following macroeconomic groups: Gross domestic product (GDP) components, Industrial production, Employment, Consumer expectations, Housing, Unemployment rate, Business inventories, Prices, Money supply, Interest rates, Wages, Exchange rates, Stock prices, and Financial conditions.

Additionally, we also consider the variance risk premium (VRP) of the equity market (Bollerslev, Tauchen, & Zhou, 2009; Hollstein & Wese Simen, 2019). We use the monthly VRP provided by Zhou (2018).[3] The author defines the VRP as deannualized VIX^2 minus the realized variance from 5-min returns over the past month. For our set of macroeconomic news announcements we use the most relevant macroeconomic news identified by the Thompson Reuters Eikon Economic Monitor. We retain the announcement dates from the webpages of the relevant institutions. We provide further details in Table A1 of the Online Appendix.

2.3 | Commodity-specific measures

Following Gorton, Hayashi, and Rouwenhorst (2012), we use the inventory data for the commodity markets and several commodity-specific variables which are presented in Table A1 of the Online Appendix. First, we use the volatility of the commodity market as a whole. As a proxy we use the standard deviation of the CRB Commodity Index. Second, we use a unique inventory variable for each commodity market, that is retained from the sources presented in Table A1 of the Online Appendix. Third, motivated by H. Hong (2000) we use the Commodity Futures Trading Commission (CFTC) data set to calculate Working's (1960) T, as a measure of speculation. We use data on trader positions from the CFTC to

[3]https://sites.google.com/site/haozhouspersonalhomepage.

TABLE 1 Summary statistics variance term structure

	Mean	*SD*	10%	50%	90%	AR(1)
Cocoa						
Vol_1	0.25	0.08	0.15	0.23	0.35	95.92
Vol_{12}	0.24	0.07	0.17	0.22	0.36	97.77
Coffee						
Vol_1	0.42	0.13	0.28	0.41	0.58	96.33
Vol_{12}	0.37	0.09	0.27	0.36	0.48	98.56
Copper						
Vol_1	0.31	0.11	0.19	0.30	0.43	95.55
Vol_{12}	0.27	0.10	0.17	0.24	0.41	99.23
Corn						
Vol_1	0.29	0.10	0.17	0.28	0.42	91.76
Vol_{12}	0.26	0.06	0.18	0.25	0.35	96.57
Cotton						
Vol_1	0.27	0.10	0.18	0.25	0.40	97.28
Vol_{12}	0.23	0.07	0.16	0.21	0.32	99.10
Crude oil						
Vol_1	0.36	0.14	0.22	0.34	0.50	97.95
Vol_{12}	0.29	0.08	0.18	0.28	0.38	96.99
Gold						
Vol_1	0.18	0.07	0.10	0.17	0.25	97.80
Vol_{12}	0.18	0.07	0.10	0.18	0.27	99.77
Natural gas						
Vol_1	0.50	0.16	0.32	0.49	0.71	97.48
Vol_{12}	0.36	0.10	0.26	0.35	0.45	93.58
Silver						
Vol_1	0.32	0.12	0.20	0.30	0.46	97.82
Vol_{12}	0.29	0.11	0.17	0.30	0.42	99.75
Soybeans						
Vol_1	0.25	0.08	0.15	0.23	0.35	95.92
Vol_{12}	0.24	0.07	0.17	0.22	0.36	97.77
Sugar						
Vol_1	0.38	0.13	0.23	0.36	0.54	96.48
Vol_{12}	0.27	0.07	0.18	0.27	0.36	98.58
Equity						
Vol_1	0.22	0.09	0.13	0.20	0.32	88.49
Vol_{12}	0.23	0.06	0.16	0.22	0.30	99.18

Note: The summary statistics for the option-implied volatility term structure are shown. It shows the annualized model-free estimate of option-implied volatility for the commodity market for monthly and annual volatilities. The volatilities are seasonally adjusted via a trigonometric function. The sample starts from 1996 through 2015. Vol_1 is the 1-month volatility, Vol_{12} is the 12-month volatility. The column *SD* presents the standard deviation, 10%, 15%, and 90% denote the respective percentiles of the distribution. Finally $AR(1)$ reports the first-order autocorrelation coefficient (in percentage points).

calculate the speculation factors. We use the historical data set provided by the CFTC with data from 1995 until 2015 that only distinguishes between commercial and non-commercial traders. Table A1 of the Online Appendix shows the CFTC contract codes and associated commodities. Following Gorton et al. (2012), we choose the newer contract when both series are overlapping and we use the last value for the monthly observation. Speculation is represented by the number of open interest from speculators, both long and short, N_L and N_S divided by the open interest of hedgers (C_L, C_S). Working's (1960) T is defined as follows:

$$\text{Working's } T = \begin{cases} 1 + \dfrac{N_S}{C_S + C_L} & if \quad C_S \geq C_L, \\ 1 + \dfrac{N_L}{C_S + C_L} & if \quad C_S < C_L. \end{cases} \tag{3}$$

If the market is short (long), only short (long) speculators determine Working's T.

Fourth, we use the basis of each commodity. Bakshi et al. (2017) show that this factor helps to price the cross-section of commodities. To calculate the basis for every commodity, we use the approach following Gorton et al. (2012) and Yang (2013) and define basis as the log difference between the 1-month futures price and the 12-month futures price scaled by the difference in time to maturity:

$$B_{i,t} = \frac{log\,(F_{i,t,T_1}) - log\,(F_{i,t,T_2})}{T_2 - T_1}. \tag{4}$$

The commodity basis reflects risk related to the convenience yield.

This results in the following factors: speculation, basis, commodity inventory, and commodity volatility. For the purpose of calculating the basis, the data set of futures is obtained from the CRB and presented in Table A1 of the Online Appendix.

3 | MAIN ANALYSIS

3.1 | Descriptive analysis

Motivated by Cochrane and Piazzesi (2005), Feunou et al. (2013), and Johnson (2017), we use information on the entire term structure to obtain unique factors of the implied commodity volatility term structure. Option markets carry forward-looking information about the underlying asset. Long-term and short-term options carry different information. Schwartz and Smith (2000) argue that long-term futures contracts carry information about the long-term equilibrium price level and short-term futures contracts provide information about the short-term price variations. Long- and short-term option-implied volatility can be interpreted in a similar vein.

We decompose the implied volatility term structure into three factors. The level factor can be seen as average volatility and is influenced less by short-term fluctuations than the slope, which loads positively on short-term volatility. In addition, we examine a curvature factor. Dissecting the different effects of the volatility term structure will help to reduce noise and provide insight into the information transmission and causal links of volatility for the commodity market.

We calculate the factors with principal component analysis (PCA), which disentangles term structure effects and creates uncorrelated orthogonal factors. All PCs are calculated by singular value decomposition of the scaled data matrix. They are standardized to have a mean of zero. Table 2 presents summary statistics that show that, combined, the three PCs explain from 82% to 95% of the total variation of the term structure of option-implied volatilities for the different commodities. In the following we separately examine the PCs.

Panel A of Table 2 shows that the *level* factor (first PC) captures 48–72% of the variation in the term structure of option-implied volatilities. It captures most of the variation for metals, where the Samuelson effect is not present (Bessembinder, Coughenour, Seguin, & Smoller, 1996; Duong & Kalev, 2008). This factor is highly persistent, as evidenced by the large AR(1) component. We use a factor rotation to ensure that the loadings on the first PC are positive. Figure A1 of the Online Appendix shows the loadings of the level factor on the components of the volatility term structure in black circles. The level factor has a loading that is almost constant over time for all observed markets.

In Panel B of Table 2 we see that the *slope* factor (second PC) captures 15–21% of the variation in the term structure of option-implied volatilities. The first-order autocorrelation is lower compared to the level. However, while for the equity market the AR(1) coefficient is only 0.79, for the commodity markets, the slope shows a higher autocorrelation of above 0.90. The loadings of the slope on the different contracts is displayed in blue triangles in Figure A1 of the Online Appendix.[4] These are consistently decreasing for all commodities, except for natural gas. The slope should be positive when the Samuelson effect is present and negative if it is not.

Panel C of Table 2 reveals that the *curvature* factor (third PC) can explain between 4% and 15% of the variation in the option-implied commodity volatility term structure. It explains the highest share of the variation for softs and agricultural commodities, where the Samuelson effect is strongest (Duong & Kalev, 2008). Surprisingly, the curvature

[4]To have a consistent interpretation of the slope estimate for all markets, we require the slope of the term structure to be downward sloping with maturity, otherwise we multiply the current rotation by −1.

TABLE 2 Principal components summary statistics

	expl. Var.(%)	*SD*	Skewness	Kurtosis	10%	25%	50%	75%	90%	AR(1)
Panel A: (Level)										
Cocoa	61	2.32	0.22	2.63	−3.06	−1.85	−0.01	1.53	2.98	99.38
Coffee	56	2.26	0.49	3.55	−2.86	−1.45	−0.21	1.39	2.88	99.01
Copper	67	2.35	1.63	6.65	−2.23	−1.65	−0.42	0.95	2.55	99.19
Corn	53	2.20	1.00	3.92	−2.38	−1.56	−0.51	1.18	3.23	98.58
Cotton	64	2.34	1.34	4.97	−2.29	−1.53	−0.65	1.04	3.13	99.37
Crude	64	2.33	1.13	5.66	−2.87	−1.55	−0.12	1.12	2.77	99.31
Gold	71	2.36	1.21	6.06	−2.87	−1.40	−0.20	1.03	2.67	99.51
Natural gas	48	2.15	0.41	2.87	−2.82	−1.69	−0.07	1.40	3.01	99.15
Silver	75	2.39	0.84	3.92	−2.90	−1.91	−0.15	1.30	3.00	99.44
Soybeans	61	2.33	1.20	3.97	−2.26	−1.68	−0.64	1.01	3.62	98.98
Sugar	65	2.35	0.45	2.91	−2.94	−1.75	−0.20	1.70	2.90	99.14
Equity	72	2.38	1.54	7.21	−2.58	−1.78	−0.33	1.15	2.69	98.59
Panel B: Slope										
Cocoa	16	0.60	−1.20	10.16	−0.58	−0.27	0.01	0.32	0.63	89.22
Coffee	18	0.74	0.23	4.21	−0.90	−0.47	0.01	0.43	0.89	94.50
Copper	17	0.61	0.32	4.78	−0.66	−0.39	−0.05	0.36	0.74	90.08
Corn	21	0.88	−0.47	3.12	−1.29	−0.58	0.19	0.62	0.98	90.70
Cotton	16	0.60	0.62	6.04	−0.63	−0.34	−0.04	0.30	0.69	93.88
Crude	16	0.59	0.47	4.24	−0.75	−0.37	−0.03	0.32	0.78	95.44
Gold	19	0.63	0.32	4.29	−0.86	−0.37	0.00	0.38	0.76	96.72
Natural gas	19	0.65	−0.21	5.15	−0.73	−0.42	0.01	0.38	0.78	90.43
Silver	16	0.51	0.66	4.92	−0.61	−0.31	−0.04	0.32	0.60	95.42
Soybeans	15	0.57	−0.61	4.11	−0.74	−0.29	0.09	0.34	0.62	91.56
Sugar	16	0.58	0.50	5.22	−0.65	−0.35	−0.02	0.31	0.70	91.41
Equity	16	0.53	1.58	11.49	−0.63	−0.30	−0.01	0.27	0.51	78.66
Panel C: Curvature										
Cocoa	10	0.38	1.58	9.44	−0.38	−0.25	−0.03	0.18	0.39	93.72
Coffee	10	0.40	−0.97	4.37	−0.58	−0.20	0.08	0.28	0.44	95.49
Copper	7	0.23	0.28	6.00	−0.25	−0.15	0.00	0.12	0.27	86.14
Corn	11	0.45	−0.14	2.63	−0.55	−0.31	−0.02	0.35	0.59	96.52
Cotton	9	0.31	−0.29	3.76	−0.41	−0.19	0.02	0.21	0.37	94.61
Crude	11	0.42	−3.53	22.50	−0.53	−0.01	0.12	0.21	0.28	92.93
Gold	4	0.14	0.57	5.03	−0.17	−0.08	−0.01	0.08	0.17	85.71
Natural gas	15	0.84	−1.12	6.17	−0.92	−0.43	0.07	0.53	1.00	96.93
Silver	4	0.13	−0.72	7.89	−0.15	−0.08	0.00	0.08	0.15	87.01
Soybeans	9	0.35	−1.86	9.09	−0.34	−0.11	0.04	0.21	0.34	94.02
Sugar	10	0.34	−0.31	4.96	−0.42	−0.26	−0.02	0.29	0.44	93.92
Equity	7	0.22	−4.20	43.00	−0.19	−0.08	0.03	0.12	0.19	37.47

Note: The summary statistics of the first three PCs, the level, the slope and curvature, of the commodity markets and the equity market are shown. Panel A presents the summary statistics for the level, while Panels B and Panel C present those for the slope and the curvature, respectively. *expl. Var.* (%) shows the variation that is explained in percent, the mean is standardized at zero and thus not reported. The column *SD* presents the standard deviation. 10%, 25%, 50%, 75%, and 90% denote the different percentiles of the distribution. Finally, $AR(1)$ reports the first-order autocorrelation coefficient (in percentage points).

factor seems for most commodities not to be less persistent than the slope factor. Especially for softs and agricultural commodities it has a higher persistence than for other sectors. The first-order autocorrelation is larger than 0.9. In contrast, for the equity market the curvature shows little first-order autocorrelation, with only 0.37. The loadings of the curvature factor are displayed with an orange plus in Figure A1 of the Online Appendix.[5] One can observe that it displays a tent-shaped factor loading on the volatility term structure. The factor loading is almost always highest for the 9-month implied volatility, with copper and gold peaking at three and sugar peaking at 6 months.

To get an initial understanding of the dependence structure of the volatility term structure across commodities, Table 3 presents the correlations of the level, slope, and curvature factors of different commodities. Additionally we investigate the correlation with the level factor of each asset and the first PC of the entire cross-section. There is a strong factor structure for the level of the volatility term structures. However, while there seems to be a strong overall common factor structure, there are also cases of negative correlations in the level factor across commodities. There is negative bivariate correlation between

[5]We require the curvature to have a larger loading for medium volatility compared to long- and short-term volatility.

coffee and commodities in the metal market (copper, silver, and gold). These results are consistent with Christoffersen et al. (2019), who show that the common PC of the commodity market realized volatility cannot explain a large degree of the realized volatility of coffee. The correlations of the PCs of the volatility term structure of one commodity with those of other commodities in the same sector are high for the metal market and the agricultural market. The sector components in the market for softs and energies are not as strong. We see a strong factor structure in the slope of the volatility term structure with the first PC of the slope: this correlation exceeds 0.2 for most commodities. The level and slope factors of the equity market are also positively correlated with those of most commodity markets.

There are several questions that we seek to answer in the remainder of this paper: Are the term-structure factors related to macroeconomic factors, sector-specific factors, or commodity market factors? What are the determinants of the commodity volatility term structure? Can the knowledge about today's volatility term structure of one commodity help improve forecasts for that of other commodities? What effect does financialization have on the common factor structure and the lead/lag factor structure? And, finally, does information transmission contribute to spillovers?

3.2 | Macroeconomic determinants

To shed light on the relationship of commodity volatility and the macroeconomy, we conduct contemporaneous multivariate regressions of the level, slope, and curvature factors of each commodity on the macroeconomic variables discussed above. Several previous studies show that there is a relation between commodity volatility and macroeconomic variables. Nguyen and Walther (2019) investigate the macroeconomic drivers of long- and short-term volatility components. They find significant drivers for global real economic activity and changes in consumer sentiment. Prokopczuk, Stancu, and Symeonidis (2019) and Kang, Nikitopoulos, and Prokopczuk (2019) analyze economic drivers of commodity market volatility and crude oil volatility and find that volatility shows strong comovement with economic and financial uncertainty, especially during crisis periods. For the softs and the agricultural market Covindassamy, Robe, and Wallen (2017) and Adjemian, Bruno, Robe, and Wallen (2018) show that macroeconomic variables and commodity-specific variables matter for the volatility.

With certain variables—for example, unemployment and employment—there could be concerns about multicollinearity. To address this, we conduct the multicollinearity test of Kovács, Petres, and Tóth (2005) and compute variance inflation factors (VIF). The Kovács et al. (2005) red indicator is a measure of redundancy, using the average correlation of the data. For our sample, the average of this measure is 0.22, which is far below the threshold of 0.5 usually applied to diagnose multicollinearity. None of the VIFs exceeds 3.1 on average, which is far below typical thresholds of 5 and 10 employed by the literature. Thus, these tests indicate that the multicollinearity does not pose a problem in the regressions.[6]

The results are shown Tables 4, 5, and 6, and we can see that certain macroeconomic factors do indeed influence the volatility term structure.

Volatility level: In Table 4 we see that the level factor is in many cases negatively related to the change in speculation, represented by Working's T, albeit this change is insignificant.

There are several macroeconomic factors that influence the volatility term structure. Employment is significantly positively related to the level factors of most commodities. For sugar and corn, though, this effect is insignificant and for silver even negative. For the softs market this also holds for unemployment, showing that the overall employment situation seems to have a V-shaped influence on the level of volatilities for this market. High employment (unemployment) implies a high (low) available income and high (low) demand, which results in increasing (increasing) expected variation in prices. These commodities are most affected by direct consumer demand. Financial conditions are positively related to volatilities of the metals market and sugar. They are negatively related to coffee, which might explain the low correlation. This result is similar to those of Kilian (2009). The housing market has a negative relationship with coffee, sugar, and natural gas for the volatility level, while the relation with the agricultural market and silver is positive. For interest rates, we largely see a negative effect on the level of volatility. It is particularly large for metals that are used for industrial purposes, for example, copper and silver. Larger interest rates indicate larger borrowing costs with, ceteris paribus, lower expected demand and lower variation. For gold, an increase in interest rates increases opportunity costs and thus might result in decreasing market demand. However, because gold is used primarily as a financial commodity, it does not benefit from the positive signal of higher interest rates with regard to the

[6]The detailed test results are available upon request.

TABLE 3 Correlations

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equity
Panel A: Level												
Cocoa	1.00	0.33	0.29	0.43	0.47	0.58	0.47	0.41	0.09	0.59	0.62	0.46
Coffee		1.00	−0.15	−0.15	−0.02	0.14	−0.17	0.29	−0.34	0.04	0.23	0.15
Copper			1.00	0.63	0.40	0.50	0.63	0.40	0.71	0.62	0.33	0.42
Corn				1.00	0.68	0.50	0.65	0.11	0.68	0.79	0.52	0.49
Cotton					1.00	0.51	0.51	0.04	0.57	0.59	0.63	0.39
Crude						1.00	0.57	0.43	0.39	0.53	0.52	0.68
Gold							1.00	0.23	0.78	0.56	0.41	0.54
Natural								1.00	0.00	0.25	0.33	0.20
Silver									1.00	0.49	0.26	0.41
Soybean										1.00	0.52	0.42
Sugar											1.00	0.52
Equity												1.00
PC_1	0.73	0.18	0.79	0.84	0.72	0.77	0.80	0.45	0.72	0.81	0.77	0.77
Panel B: Slope												
Cocoa	1.00	0.28	0.06	0.27	0.04	0.09	0.10	0.11	0.07	0.20	0.09	0.14
Coffee		1.00	0.09	0.36	0.03	−0.13	0.10	0.17	−0.02	0.34	0.23	−0.02
Copper			1.00	0.13	0.12	0.36	0.34	−0.06	0.34	0.13	0.16	0.29
Corn				1.00	0.26	−0.12	0.20	−0.14	0.01	0.68	0.19	0.07
Cotton					1.00	0.00	0.06	−0.03	0.01	0.27	0.21	0.02
Crude						1.00	0.44	−0.02	0.45	−0.08	0.02	0.42
Gold							1.00	−0.10	0.74	0.16	0.25	0.48
Natural								1.00	−0.07	−0.05	−0.04	−0.05
Silver									1.00	0.02	0.18	0.50
Soybean										1.00	0.23	0.03
Sugar											1.00	−0.01
Equity												1.00
PC_1	0.42	0.15	0.44	0.47	0.22	0.55	0.85	−0.15	0.73	0.35	0.28	0.73
Panel C: Curvature												
Cocoa	1.00	0.41	0.33	−0.54	−0.27	0.20	−0.03	0.00	0.25	−0.19	0.68	−0.00
Coffee		1.00	0.09	−0.09	−0.16	0.17	0.00	0.13	0.18	−0.08	0.30	0.09
Copper			1.00	−0.38	−0.19	0.05	−0.04	−0.13	0.09	−0.16	0.33	0.02
Corn				1.00	0.41	−0.04	0.02	0.09	−0.16	0.49	−0.55	−0.06
Cotton					1.00	0.13	−0.06	0.14	−0.19	0.37	−0.37	−0.08
Crude						1.00	−0.12	0.09	−0.03	0.06	0.15	−0.02
Gold							1.00	0.05	0.11	0.02	−0.12	0.17
Natural								1.00	0.13	−0.09	−0.03	0.07
Silver									1.00	−0.10	0.22	0.10
Soybean										1.00	−0.28	−0.08
Sugar											1.00	−0.05
Equity												1.00
PC_1	0.85	0.71	0.52	−0.80	−0.61	0.01	−0.04	−0.15	0.34	−0.48	0.83	0.06

Note: The correlation of the PCs across different commodities as well as that of the S&P 500. In Panel A, we show the correlations for the level factor, in Panel B those for the slope factor and in Panel C those for the curvature factor. Below each panel. PC_1 displays the correlation of the PCs with the first PC of the respective factor over all commodity markets.

stability of the economy. This effect can, on the contrary, indicate that prices of gold fall further, because the demand for hedges against an economic crisis decreases. This will likely result in increasing volatilities. For other commodities this will not occur in the same magnitude when inventories are not so low. For the volatility level of corn and gold, we see a negative relation with money supply. The macroeconomic and commodity-specific factors are generally able to explain a large proportion of the variation in the level factor. The R^2s range between 34.52% for gold and up to 57.75% for corn.

Volatility slope: Table 5 shows the results for the slope of the implied commodity volatility term structures. According to the theory of storage, we would expect to have either a significant positive relationship with the basis or a negative relationship with the inventory variables. There are three hypothesis that explain when the Samuelson (1965) theory could be violated. H. Hong (2000) states that information asymmetry in markets can lead to violations of the Samuelson hypothesis. Fama and French (1988) argue that around business cycle peaks, when inventory is low, the Samuelson hypothesis should hold, while the theory can be violated if inventory is high and marginal convenience yields are low. Bessembinder et al. (1996) argue that the existence of a temporary component that is reversed over

TABLE 4 Macroeconomic determinants—level

	Cocoa	Coffee	Cotton	Sugar	Corn	Soybeans	Copper	Gold	Silver	Crude	Natural Gas
Business inventory	−0.39**	−0.17	−0.40**	−0.19	0.08	−0.34**	0.31**	−0.40**	0.37	0.14	0.04
	(0.16)	(0.16)	(0.19)	(0.29)	(0.17)	(0.14)	(0.14)	(0.16)	(0.25)	(0.10)	(0.10)
Commodity volatility	0.01	0.34**	0.33**	−0.67*	0.04	0.07	0.43**	−0.19	0.50***	0.27**	−0.02
	(0.18)	(0.14)	(0.14)	(0.39)	(0.26)	(0.26)	(0.21)	(0.24)	(0.16)	(0.13)	(0.11)
Consumer expectations	0.06	0.22**	0.01	−0.11	−0.11	−0.24	0.09	0.04	−0.07	0.11	0.06
	(0.09)	(0.09)	(0.11)	(0.21)	(0.10)	(0.17)	(0.11)	(0.10)	(0.11)	(0.08)	(0.09)
Employment	0.79***	0.53***	0.34***	0.26	0.03	0.33**	0.33**	0.26**	−0.35***	0.61***	0.63***
	(0.14)	(0.12)	(0.12)	(0.23)	(0.10)	(0.14)	(0.13)	(0.10)	(0.13)	(0.07)	(0.10)
Exchange rates	−0.00	0.00	−0.01	0.13	−0.10	−0.17	−0.10	−0.07	0.01	−0.03	−0.16***
	(0.09)	(0.06)	(0.09)	(0.13)	(0.06)	(0.13)	(0.10)	(0.07)	(0.13)	(0.07)	(0.06)
Financial conditions	−0.05	−0.97***	0.05	1.74**	0.40	0.08	0.37**	0.32	0.63***	−0.09	−0.27
	(0.34)	(0.22)	(0.28)	(0.74)	(0.25)	(0.20)	(0.18)	(0.23)	(0.23)	(0.15)	(0.18)
GDP	0.29	0.12	0.07	1.01***	0.19	0.22	−0.13	0.12	−0.29	0.10	0.19
	(0.21)	(0.16)	(0.22)	(0.37)	(0.19)	(0.27)	(0.23)	(0.23)	(0.24)	(0.13)	(0.19)
Housing	−0.06	−0.48***	0.20	−3.58***	0.73**	1.01***	0.17	0.38	0.39**	−0.02	−0.37***
	(0.09)	(0.10)	(0.21)	(1.10)	(0.29)	(0.23)	(0.13)	(0.25)	(0.17)	(0.09)	(0.09)
Industrial production	−0.05	−0.02	−0.19*	−0.36**	−0.32***	−0.02	0.18*	−0.19	−0.13	0.04	0.22**
	(0.09)	(0.07)	(0.10)	(0.16)	(0.12)	(0.08)	(0.11)	(0.12)	(0.11)	(0.08)	(0.10)
Interest rates	−0.20	−0.21	−0.43**	0.12	−0.30	−0.86**	−0.69**	0.34	−0.99***	−0.75***	0.26
	(0.36)	(0.21)	(0.20)	(0.42)	(0.24)	(0.36)	(0.29)	(0.21)	(0.34)	(0.18)	(0.22)
Money	−0.02	−0.00	−0.02	0.06	−0.11***	−0.01	−0.03	−0.12***	−0.01	−0.04	0.03
	(0.03)	(0.05)	(0.04)	(0.09)	(0.02)	(0.02)	(0.04)	(0.03)	(0.04)	(0.04)	(0.03)
Prices	−0.07	0.07	0.04	−0.51***	−0.02	0.12	0.09	−0.10	0.08	0.01	−0.04
	(0.08)	(0.06)	(0.11)	(0.14)	(0.08)	(0.09)	(0.08)	(0.06)	(0.09)	(0.05)	(0.05)
Stock prices	−0.02	0.05	0.12	−0.01	−0.03	−0.05	−0.04	0.02	0.09	0.01	−0.10*
	(0.08)	(0.07)	(0.08)	(0.14)	(0.05)	(0.06)	(0.07)	(0.08)	(0.10)	(0.06)	(0.06)
Unemployment	0.23**	0.26***	0.24*	−0.04	−0.43***	0.14	−0.02	0.04	−0.23*	0.17*	0.20*
	(0.11)	(0.10)	(0.13)	(0.15)	(0.13)	(0.10)	(0.13)	(0.08)	(0.13)	(0.09)	(0.11)
Wages	−0.43*	0.23	−0.44**	−0.76	−0.11	0.37*	−0.84***	−0.28	−0.38	−0.22	0.19
	(0.25)	(0.20)	(0.18)	(0.52)	(0.14)	(0.20)	(0.24)	(0.24)	(0.35)	(0.18)	(0.18)
Working's T	−0.19**	−0.04	−0.03	0.15	−0.15	−0.07	−0.05	−0.02	−0.10	−0.00	−0.06
	(0.08)	(0.10)	(0.11)	(0.23)	(0.19)	(0.09)	(0.16)	(0.05)	(0.10)	(0.12)	(0.08)
Basis	−0.34	0.17	0.10	0.39	−0.09	−0.60***	0.51**	−0.02	0.25	−0.11	−0.46**
	(0.43)	(0.32)	(0.44)	(0.36)	(0.17)	(0.15)	(0.24)	(0.33)	(0.52)	(0.22)	(0.21)
Commodity inventory	0.15	0.13	−0.04	−0.29**	0.09	0.06	0.05	−0.44***	0.00	−0.14	0.10
	(0.18)	(0.11)	(0.11)	(0.14)	(0.11)	(0.10)	(0.13)	(0.13)	(0.20)	(0.15)	(0.19)
Adj. R^2 (%)	36.55	40.23	44.48	55.47	55.65	45.44	42.16	34.52	52.23	57.75	46.47

Note: We conduct month-end contemporaneous regressions of the commodities' level factors on macroeconomic components. These are computed using the first PC of the macroeconomic groups in Table A1 of the Online Appendix as independent variables. *, **, ***, respectively, indicate significance at the 10%, 5%, and 1% level, using Newey and West (1986) standard errors with 10 lags.

time is the main factor that determines if the Samuelson hypothesis holds in a market. A positive shock leads to a reversal over time. They find that the Samuelson hypothesis is empirically supported in markets where spot price changes and the slope of the term structure covary negatively. Tightening inventories reduces the possibility for markets to react to increases in demand or supply shortages. Therefore we should investigate the basis, the inventory and Working's T with regard to their expected relation with the slope of the volatility term structure.

The basis is seen as a proxy for inventory levels. It is positive if the price of a 1-month contract is larger than the price of a 12-month contract. This occurs when the commodity is in backwardation, a state which is associated with tighter inventories. Contango, on the other hand, is associated with abundant inventories. The theory of storage can be supported for cocoa, silver, copper, and natural gas. For these commodities we have either a significant positive relationship with the basis or a negative relationship with the inventory variable. The observations for gold, crude oil, corn, and soybeans are not consistent with the theory of storage.

TABLE 5 Macroeconomic determinants—slope

	Cocoa	Coffee	Cotton	Sugar	Corn	Soybeans	Copper	Gold	Silver	Crude	Natural gas
Business inventory	−0.05	−0.02	−0.05	0.06	−0.10	−0.20**	−0.00	−0.03	0.03	0.17***	−0.02
	(0.04)	(0.06)	(0.08)	(0.04)	(0.19)	(0.09)	(0.04)	(0.06)	(0.04)	(0.06)	(0.05)
Commodity volatility	0.07**	0.05	−0.03	−0.08	0.31**	0.08	0.13***	−0.07	0.14***	0.01	−0.05
	(0.03)	(0.04)	(0.04)	(0.07)	(0.15)	(0.12)	(0.03)	(0.07)	(0.04)	(0.04)	(0.04)
Consumer expectations	−0.02	0.01	0.02	−0.00	−0.08	0.05	−0.00	−0.06	−0.02	−0.03	0.05
	(0.03)	(0.04)	(0.03)	(0.08)	(0.16)	(0.09)	(0.03)	(0.03)	(0.02)	(0.03)	(0.05)
Employment	0.03	−0.07	0.03	−0.14***	−0.04	0.05	0.10***	0.09**	0.05*	0.01	0.03
	(0.02)	(0.04)	(0.05)	(0.05)	(0.13)	(0.07)	(0.03)	(0.04)	(0.03)	(0.03)	(0.05)
Exchange rates	0.01	−0.03	−0.04	0.02	0.00	−0.08	0.02	−0.02	−0.01	−0.01	−0.06*
	(0.02)	(0.04)	(0.03)	(0.06)	(0.08)	(0.06)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Financial conditions	0.03	0.03	0.01	0.04	−0.21	−0.06	−0.29***	−0.08	−0.07*	−0.01	0.03
	(0.04)	(0.07)	(0.05)	(0.07)	(0.15)	(0.09)	(0.05)	(0.06)	(0.04)	(0.07)	(0.08)
GDP	−0.05	0.00	−0.08	0.02	0.31	−0.11	0.05	−0.08	−0.01	−0.02	−0.07
	(0.05)	(0.06)	(0.05)	(0.10)	(0.26)	(0.10)	(0.05)	(0.05)	(0.06)	(0.06)	(0.08)
Housing	−0.08***	−0.02	−0.03	−0.38***	−0.19	0.10	−0.12***	−0.03	−0.14***	−0.06**	0.03
	(0.02)	(0.03)	(0.05)	(0.12)	(0.28)	(0.11)	(0.03)	(0.06)	(0.02)	(0.03)	(0.04)
Industrial production	−0.01	−0.01	0.01	0.01	−0.05	0.00	0.01	0.07**	−0.04	0.00	0.04
	(0.02)	(0.04)	(0.03)	(0.05)	(0.13)	(0.05)	(0.03)	(0.03)	(0.02)	(0.03)	(0.05)
Interest rates	0.01	0.04	0.08	−0.30***	0.28	0.10	−0.03	0.02	0.00	−0.09	−0.17
	(0.05)	(0.10)	(0.08)	(0.10)	(0.17)	(0.18)	(0.08)	(0.07)	(0.06)	(0.11)	(0.13)
Money	0.01	0.04***	−0.02***	0.10**	−0.07**	−0.02	−0.02	−0.06**	−0.02**	−0.03**	0.02
	(0.01)	(0.01)	(0.01)	(0.04)	(0.03)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)
Prices	0.02	0.00	−0.03	0.07	−0.04	−0.02	0.01	−0.00	0.00	0.02	−0.03
	(0.02)	(0.03)	(0.03)	(0.06)	(0.10)	(0.06)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Stock prices	0.01	0.09***	−0.02	−0.05*	0.00	0.03	0.02	−0.03	0.05***	−0.04**	0.01
	(0.02)	(0.03)	(0.02)	(0.03)	(0.04)	(0.04)	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)
Unemployment	−0.03	−0.02	0.02	−0.01	0.12	−0.02	0.02	0.02	−0.02	0.03	0.03
	(0.03)	(0.04)	(0.04)	(0.06)	(0.12)	(0.09)	(0.04)	(0.02)	(0.03)	(0.03)	(0.04)
Wages	0.06	−0.12	−0.07	0.04	−0.01	0.02	−0.01	0.22***	0.01	−0.07	−0.11
	(0.05)	(0.08)	(0.05)	(0.08)	(0.26)	(0.13)	(0.07)	(0.06)	(0.09)	(0.07)	(0.10)
Working's T	−0.02	−0.11***	−0.03	−0.16	0.19	−0.02	0.03	0.00	0.03	0.15***	−0.01
	(0.03)	(0.04)	(0.03)	(0.12)	(0.17)	(0.06)	(0.05)	(0.02)	(0.03)	(0.04)	(0.03)
Basis	0.14***	0.06	0.09	0.00	−0.22*	−0.20**	0.00	−0.09	0.14***	0.11	0.04
	(0.05)	(0.09)	(0.11)	(0.11)	(0.11)	(0.08)	(0.06)	(0.08)	(0.05)	(0.08)	(0.09)
Commodity inventory	−0.00	0.03	0.03	0.08	−0.12	−0.09	−0.15***	0.07*	0.01	0.08*	−0.12*
	(0.04)	(0.04)	(0.03)	(0.06)	(0.08)	(0.06)	(0.05)	(0.04)	(0.04)	(0.05)	(0.07)
Adj. R^2 (%)	12.49	5.409	−1.858	28.83	−0.6	−9.961	32.73	30.36	39.50	32.65	3.254

Note: We conduct month-end contemporaneous regressions of the commodities' slope factors on macroeconomic components. These are computed, using the first PC of the macroeconomic groups in Table A1 of the Online Appendix as independent variables. *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% level, using Newey and West (1986) standard errors with 10 lags.

TABLE 6 Macroeconomic determinants—curvature

	Cocoa	Coffee	Cotton	Sugar	Corn	Soybeans	Copper	Gold	Silver	Crude	Natural gas
Business inventory	0.01	−0.01	0.07*	−0.02	−0.11	−0.12	0.01	0.01*	−0.01	0.00	−0.11*
	(0.02)	(0.02)	(0.04)	(0.05)	(0.10)	(0.10)	(0.02)	(0.01)	(0.01)	(0.02)	(0.07)
Commodity volatility	0.01	0.03	−0.01	−0.04	0.06	−0.12	−0.01	0.01	0.01	0.01	−0.00
	(0.02)	(0.02)	(0.03)	(0.05)	(0.12)	(0.13)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)
Consumer expectations	0.01	−0.00	0.00	0.06	0.04	0.10	−0.01	0.01	−0.02*	−0.00	0.05
	(0.02)	(0.02)	(0.02)	(0.04)	(0.07)	(0.12)	(0.01)	(0.01)	(0.01)	(0.01)	(0.06)
Employment	0.01	0.05**	−0.05**	0.02	−0.07	−0.07	−0.01	0.02***	0.02**	0.03**	0.06
	(0.02)	(0.02)	(0.02)	(0.02)	(0.07)	(0.07)	(0.01)	(0.01)	(0.01)	(0.01)	(0.07)
Exchange rates	−0.01	−0.03**	−0.01	−0.06*	0.14***	0.10	−0.01	0.01	0.01	−0.01	0.06
	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.09)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)
Financial conditions	0.02	0.02	0.04	0.12**	−0.04	0.01	0.00	0.00	−0.00	0.00	0.15
	(0.04)	(0.04)	(0.03)	(0.05)	(0.10)	(0.12)	(0.02)	(0.01)	(0.01)	(0.02)	(0.12)
GDP	0.02	−0.01	−0.00	−0.09	0.27**	0.04	0.00	0.00	0.01	0.05	0.05
	(0.02)	(0.04)	(0.03)	(0.10)	(0.12)	(0.11)	(0.02)	(0.01)	(0.02)	(0.05)	(0.09)
Housing	0.01	−0.01	0.06	−0.02	−0.23	−0.07	0.00	−0.02	−0.01**	0.03*	0.02
	(0.01)	(0.02)	(0.04)	(0.09)	(0.16)	(0.14)	(0.01)	(0.01)	(0.01)	(0.02)	(0.04)
Industrial production	−0.01	0.02	0.01	0.02	−0.04	−0.13*	−0.01	−0.00	−0.00	0.01	−0.09
	(0.01)	(0.01)	(0.02)	(0.03)	(0.07)	(0.06)	(0.01)	(0.01)	(0.01)	(0.01)	(0.06)
Interest rates	−0.04	−0.04	0.00	0.08	0.19	0.37**	0.00	−0.00	−0.01	0.01	−0.11
	(0.06)	(0.06)	(0.04)	(0.07)	(0.13)	(0.16)	(0.03)	(0.02)	(0.02)	(0.03)	(0.16)
Money	0.01	0.01	0.00	0.00	0.06***	0.00	0.01*	−0.00	−0.00	0.02**	−0.05
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.03)	(0.00)	(0.00)	(0.00)	(0.01)	(0.03)
Prices	−0.01	−0.00	0.00	0.02	−0.11	−0.07	−0.01	0.01	−0.01	−0.03	−0.02
	(0.01)	(0.01)	(0.02)	(0.04)	(0.06)	(0.05)	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)
Stock prices	0.02*	0.01	−0.02	0.04	−0.04*	−0.02	0.02	0.02**	0.01	0.00	0.05
	(0.01)	(0.01)	(0.02)	(0.03)	(0.02)	(0.04)	(0.01)	(0.01)	(0.01)	(0.02)	(0.04)
Unemployment	−0.01	0.00	0.01	0.01	0.15***	−0.03	−0.02	0.02*	−0.00	−0.01	−0.03
	(0.01)	(0.02)	(0.03)	(0.03)	(0.05)	(0.07)	(0.01)	(0.01)	(0.02)	(0.02)	(0.06)
Wages	−0.04	0.06	−0.08**	−0.05	0.00	−0.07	−0.03	−0.02	0.05**	0.08***	−0.25**
	(0.04)	(0.04)	(0.04)	(0.04)	(0.08)	(0.09)	(0.03)	(0.01)	(0.02)	(0.03)	(0.10)
Working's T	0.00	0.00	−0.01	0.02	0.17**	0.00	0.01	−0.00	−0.00	0.00	0.01
	(0.01)	(0.02)	(0.02)	(0.09)	(0.08)	(0.04)	(0.02)	(0.00)	(0.01)	(0.03)	(0.06)
Basis	0.03	−0.11**	−0.07	0.15**	0.07	0.05	−0.03	−0.02	0.00	0.01	−0.11
	(0.04)	(0.06)	(0.05)	(0.06)	(0.07)	(0.07)	(0.02)	(0.02)	(0.01)	(0.04)	(0.09)
Commodity inventory	−0.11***	−0.01	−0.02	0.04	−0.00	−0.04	−0.02	0.01	0.01	0.05	−0.26**
	(0.02)	(0.03)	(0.02)	(0.03)	(0.05)	(0.05)	(0.02)	(0.01)	(0.01)	(0.04)	(0.12)
Adj. R^2 (%)	24.88	19.78	16.16	12.81	4.863	−10.34	−1.896	24.40	8.223	15.54	18.63

Note: We conduct month-end contemporaneous regressions of the commodities' curvature factors on macroeconomic components. These are computed, using the first PC of the macroeconomic groups in Table A1 of the Online Appendix as independent variables. *, **, and ***, respectively indicate significance at the 10%, 5%, and 1% level, using Newey and West (1986) standard errors with 10 lags.

For the slope, we see a negative relation of financial conditions for copper and silver. As we have seen before, in good financial conditions the level of the volatility term structure increases, while the term structure becomes increasingly flat. The market expects long-term inventory to decrease, which leads to an increasing volatility in the future. We also observe a significant negative relationship between many of the commodities and the housing market. A housing crisis leads to a larger slope for sugar, cocoa, industrial metals and crude oil.

For the money supply, the largest relation can be seen in the slope. For coffee and sugar there is a positive relationship. Corn, cotton, gold, silver, and crude oil have a negative relationship. The higher the money supply the lower is the slope, so a higher money supply could increase inflation expectations and long-term volatilities. For corn and gold an increasing money supply leads to a lower overall level of the volatility term structure: the lower slope indicates that the money supply particularly affects short-term volatilities for corn and gold.

For the slope, most variables have high explanatory value. However, part of the markets for which the Samuelson hypothesis typically holds appear to be driven driven by idiosyncratic factors (e.g., cocoa, coffee, cotton, corn, and soybeans). For speculation we can observe no effect for the entire market, in contrast to H. Hong (2000), who finds that information asymmetry could lead to a violation of the Samuelson effect. He captures this effect in a model, where hedgers trade without fundamental market information and speculators trade on their information advantage. Uninformed hedgers trade for hedging reasons, which is why they are willing to trade with informed investors. Due to a larger impact of nonmarketed risk in shorter-term futures. H. Hong (2000) further argues that cost in trading increases for the uninformed investor and they will trade less. He terms this effect a "speculative effect" that can overwhelm the Samuelson effect, and this holds even assuming a homogeneous information flow.

Volatility curvature: The results for the curvature factor are shown in Table 6. The curvature shows a positive relation with speculation only for corn. An increase in speculation decreases the level of the term structure, and introduces a concave shape. For coffee, sugar, and corn the curvature is related to the exchange rate, for coffee and sugar a depreciating US-Dollar is related to a concave term structure, and for corn this is related to a convex term structure. Assuming that the Samuelson effect holds, this implies a higher medium-term volatility for a negative relation and a lower medium-term volatility for a positive relation. For coffee and sugar, the United States is a net importer, a depreciating currency will only increase local demand and increase the price in US-Dollar. For corn the United States is also a major exporter, having an effect on the cost of supply. For supplies, a depreciating US-Dollar implies lower relative costs for producers in the United States, enabling them to better compete and possibly increase supply. This has calming effects on the price volatility for these commodities. The variables can generally explain a large share of the variation in the curvature for the softs market. For the remaining commodity markets, the R^2s are generally smaller.

In summary, we find that macroeconomic variables can explain a large proportion of the variation in the level factor, but typically somewhat smaller shares of the slope and curvature factors.

3.3 | Spillovers

Having documented a strong linear contemporaneous relationship between the volatility term structure factors and macroeconomic determinants, we investigate whether there are spillovers, that is, lead/lag effects, in the volatility term structures. Volatility spillovers might vary in different economic states. During periods of distress, macroeconomic effects likely lead to a strong positive lead/lag relationship for most commodities. But the role of some commodities during a crisis could be different. For example, gold is often seen as a hedge against the equity market and might react differently to a macroeconomic shock than other commodities.

We, therefore, investigate state-dependent spillovers in risk, using a Value at Risk (VaR) approach. To construct state-dependent indicator variables we use the returns of an equally weighted commodity portfolio with a 5% VaR. We use the resulting time series with the percentiles of distressed or tranquil periods as in Adams, Füss, and Gropp (2014). We, therefore, consider three indicator variables, I_D, I_T, and I_N, for distress, tranquil and normal periods, respectively. The variables are 1 if the VaR is in the defined α percentile. We follow Adams et al. (2014) and define the lower bound as 12.5% and the upper bound as 75%. Thus every observation below the 12.5% percentile indicates distress. Every observation above the 75% percentile indicates tranquil periods and everything in between shows normal economic states.[7] Adams et al. (2014) argue that these percentiles represent a good trade-off between power and an accurate representation of the state of the relevant market.

To estimate the VaR we use the CAViaR introduced by Engle and Manganelli (2004), which is able to capture volatility clustering and time varying error distributions. Engle and Manganelli (2004) specify the approach as follows:

$$\text{VaR}_t(\theta) = \theta_0 + \sum_{j=1}^{q} \theta_j \text{VaR}_{t-j}(\theta) + \sum_{i=1}^{r} \theta_{(q+i)} L(Y_{t-i}). \tag{5}$$

The AR components $\text{VaR}_{t-j}(\theta)$ introduce persistence in the VaR series which assures its continuity. The lag operator $L(Y_{t-i})$ introduces the link to the underlying data set. For our purpose we use the asymmetric slope model by Engle and Manganelli (2004) as a specification for $L(Y_{t-i})$. This model is also used by Y. Hong, Liu, and Wang (2009) for the

[7]This implies a transformation of the otherwise positively defined VaR, which we define to be negative.

estimation of the VaR and is correctly specified for a GARCH process with asymmetrically modeled standard deviation and i.i.d. errors. This is the specification of the asymmetric slope model:

$$\mathrm{VaR}_t(\theta_l) = \theta_0 + \theta_1 VaR_{t-1} + \theta_2 Y_{t-1}^{+} + \theta_3 Y_{t-1}^{-}, \tag{6}$$

where $Y_t^+ = \max(Y_t, 0)$, $Y_t^- = -\min(Y_t, 0)$. The resulting 5% VaR estimate for an equally weighted commodity portfolio is shown in Figure A2 of the Online Appendix. To obtain coefficients for a spillover analysis, we estimate a regression following the spirit of Adams et al. (2014). Our conditioning variable is not the LHS variable, but a commodity VaR Index. Hence, we cannot use quantile regressions. Instead, as described above, we introduce different economic states using dummy variables.

As control variables, we use the VRP and the corresponding PC of the equity market (PCE):[8]

$$\begin{aligned}\mathrm{PC}_{i,t} = &\sum_{k=1}^{p}\beta_k^1 \mathrm{PC}_{i,t-k}\cdot I_N + \sum_{k=1}^{p}\beta_k^2 \mathrm{PC}_{i,t-k}\cdot I_T + \sum_{k=1}^{p}\beta_k^3 \mathrm{PC}_{i,t-k}\cdot I_D \\ &+ \sum_{u=1}^{p}\gamma_u^1 \mathrm{PC}_{j,t-u}\cdot I_N + \sum_{u=1}^{p}\gamma_u^2 \mathrm{PC}_{j,t-u}\cdot I_T + \sum_{u=1}^{p}\gamma_u^3 \mathrm{PC}_{j,t-u}\cdot I_D + \mathrm{VRP}_t + \mathrm{PCE}_t + \epsilon_t.\end{aligned} \tag{7}$$

$\mathrm{PC}_{i,t-k}$ is the PC of asset i with lag k. We conclude that the term structure components of assets j spill over to those of asset i if the following null hypotheses can be rejected. We conduct four separate tests, with $H_0: \gamma_u^1 = 0$ we test if we observe any significant spillover effects during normal periods. For γ_u^2 and γ_u^3 we conduct the same test for tranquil and distressed periods, respectively. Additionally, we conduct a test investigating whether all three variables are jointly zero, $H_0: \gamma_u^1 = \gamma_u^2 = \gamma_u^3 = 0$.

We further test whether the results are economically significant by performing an out-of-sample test. We examine whether we can improve the forecast of the implied volatility term structure when we have knowledge of the implied volatility term structure of another commodity. We follow Goyal and Welch (2007) to conduct an out-of-sample analysis. We test the forecast from the unrestricted AR regression including the components of asset j against a restricted AR process that sets coefficients $H_0: \gamma_u^1 = \gamma_u^2 = \gamma_u^3 = 0$. For the purpose of the out-of-sample analysis, we assign the dummies based on forecasts that use only information available at time $t-1$.

We measure the out-of-sample performance with the following formula:

$$R_{\mathrm{OOS}}^2 = 1 - \frac{\mathrm{MSE}_{\mathrm{un}}}{\mathrm{MSE}_{\mathrm{re}}}, \tag{8}$$

where $\mathrm{MSE}_{\mathrm{un}}$ is the mean squared error of the unrestricted forecast and $\mathrm{MSE}_{\mathrm{re}}$ is the mean squared error of the restricted forecast. The restricted model assumes that $\gamma_u^1 = \gamma_u^2 = \gamma_u^3 = 0$ cannot be rejected.

We present the results of the state-dependent spillover test in Table 7. The level factor is in Panel A, the slope factor in Panel B and the curvature factor in Panel C. If the numbers are bold, the null hypothesis of zero predictability is rejected out-of-sample, using the McCracken (2007) OOS-F statistics, with a significance level of 10%. The in-sample significance is displayed with Newey and West (1986) standard errors with 10 lags. As argued by Goyal and Welch (2007), in-sample predictability is a key requirement. Table 7 shows large bivariate spillovers between commodity markets for the different term structure factors. They are significant for a large number of commodities and large in size. Tables A3, A4, and A5 of the Online Appendix further present the results of the out-of-sample tests for the different economic states. Table 8 summarizes the information in these tables. In general Table 8 shows that spillovers in distress are large in size, while during tranquil periods they are large in frequency. Thus a state-dependent approach unveils differences in spillovers between states.

Volatility level: In the following, we discuss the spillovers in level (Panel A of Table 7) in more detail. The equity market shows spillovers especially to commodity markets that are related to the business cycle, like crude oil, silver, copper, and gold. A prediction that accounts for spillovers from the equity market to the gold, copper, crude oil, and silver markets yields out-of-sample R^2's of 1.71%, 2.22%, 2.63%, and 2.80%, respectively. A potential explanation for this

[8]To uncover the relationship with the stock market we conduct a regression with the stock market's PC. In this case, we treat it like a PC of a commodity and consequently drop the PCE from the set of control variables.

TABLE 7 Spillovers between markets

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equity
Panel A: Level												
Cocoa		**1.61*** **	**1.21**	**2.09**	**2.90*** **	**2.79*** **	**3.78*** **	**0.68*** **	**2.10*** **	**1.04**	**2.02*** **	**1.86*** **
Coffee	**1.54**		**0.63**	**1.62** **	**3.86**	**3.49*** **	**0.58*** **	**3.63* **	**1.37*** **	**0.52**	**0.84** **	**0.63* **
Copper	**1.36*** **	**0.45**		**1.33**	**0.80**	**1.92* **	**2.66*** **	**0.39* **	**3.51*** **	**1.60** **	**1.78* **	**2.22*** **
Corn	**2.39** **	**1.66**	**1.16* **		**0.46**	**1.74*** **	**2.12*** **	**1.84**	**2.53*** **	**1.74** **	**1.40*** **	**0.98**
Cotton	**0.73**	**1.00**	**1.36**	**1.48**		**1.28*** **	**0.88**	**1.94**	**2.57**	**2.32*** **	**1.71** **	**0.68**
Crude	**1.11** **	**1.39*** **	**2.24** **	**1.46**	**2.29** **		**2.03*** **	**0.26**	**2.11*** **	**2.35*** **	**2.85** **	**2.63*** **
Gold	**1.37*** **	**0.95** **	**2.58*** **	**1.68** **	**1.95*** **	**1.93*** **		**2.93**	**3.15*** **	**0.79** **	**1.35*** **	**1.71*** **
Natural	**0.79**	**2.36**	**0.35*** **	**3.05** **	**8.15*** **	**1.17*** **	**1.36**		**1.03*** **	**2.30** **	**0.34** **	**1.49*** **
Silver	**1.43* **	**1.33**	**2.10** **	**2.31**	**1.67*** **	**3.24*** **	**2.71*** **	**1.41** **		**0.30**	**1.73**	**2.80*** **
Soybean	**0.89*** **	**0.47*** **	**2.81*** **	**1.54**	**1.19** **	**2.26** **	**1.44*** **	**3.44** **	**0.52** **		**0.57*** **	**0.58* **
Sugar	**1.49**	**0.36*** **	**0.43**	**2.30* **	**1.43*** **	**4.09** **	**0.56**	**0.33*** **	**1.52*** **	**0.11**		**0.20*** **
Equity	−0.33***	−0.14***	**1.68*** **	**0.43**	0.01***	**2.02*** **	**0.13*** **	**0.98*** **	**2.91*** **	**0.17**	**0.27*** **	
Panel B: Slope												
Cocoa		**0.70*** **	**0.99**	**0.68*** **	−1.42	−0.75***	−0.92	−0.94***	**0.45**	−0.10***	−2.78	−1.67***
Coffee	**0.79*** **		−0.37	**1.04*** **	**2.94* **	**3.53*** **	**0.91**	**1.54*** **	−0.30	**0.18* **	**0.78*** **	−0.04***
Copper	**0.67**	**0.48* **		−0.06	**0.68* **	**0.66*** **	**1.65* **	**0.19* **	**1.60*** **	**0.56**	**1.86**	**1.01**
Corn	**1.71*** **	**3.16*** **	**0.72**		−0.11	**1.66*** **	**1.60**	**3.33*** **	−2.24*	**2.23*** **	**0.32** **	**0.85*** **
Cotton	**0.30** **	**1.32**	**0.87*** **	**1.35*** **		**0.39**	**1.06**	**1.02*** **	**1.10**	**0.98**	**2.61*** **	**0.84*** **
Crude	**1.22**	**0.68* **	**1.12** **	**2.14*** **	**1.37**		**2.70* **	**0.95*** **	**1.90**	**0.51**	**0.51**	**0.01*** **
Gold	**0.79* **	**0.32* **	**1.06**	**0.68*** **	**1.03*** **	**1.90*** **		**2.89*** **	**4.09*** **	**1.65**	**1.28*** **	**1.07*** **
Natural	−0.93	−1.46	−0.04	**1.31** **	**3.28**	**0.12*** **	**1.41**		−0.31*	−2.26	−2.02	−0.77***
Silver	**1.18* **	**1.45** **	**0.27**	**0.72**	**1.22**	**0.72*** **	**1.38** **	**0.38*** **		**0.61**	**3.75**	**2.29*** **
Soybean	**0.49**	**2.30*** **	**1.19**	**1.50*** **	**0.38**	**0.40**	**0.98** **	**1.19*** **	0.08***		**0.88*** **	**1.03* **
Sugar	**1.30**	−0.43*	−2.03***	**0.46** **	**2.09*** **	**1.32*** **	−1.27***	**0.21*** **	**2.41*** **	**0.20**		1.61**
Equity	11.16***	−6.43	−2.28	−7.42	−8.19	−2.56***	−13.13***	−2.70***	−0.07***	**0.13**	−5.05	
Panel C: Curvature												
Cocoa		−0.18***	**1.29*** **	**1.82** **	**-0.54** **	**0.90*** **	**0.80**	**1.00**	**2.72*** **	**1.04**	**3.60*** **	**1.49*** **
Coffee	**0.67* **		**0.81**	**0.07** **	**1.66**	**3.36**	**1.42**	**3.00*** **	**1.98*** **	**0.18*** **	−0.06***	−0.38***
Copper	**1.12*** **	**0.31**		**1.13*** **	**1.04** **	**0.48**	**0.62** **	**0.25*** **	**0.50* **	**0.45**	**1.72*** **	**0.83**
Corn	**2.49*** **	**2.10**	**1.20*** **		**4.17** **	**0.61**	**1.15**	**4.09*** **	**1.25* **	**1.35**	−0.13***	**1.42*** **
Cotton	**1.15**	**1.37* **	**0.89*** **	**0.31**		**1.17**	**0.55* **	**0.74**	**2.35**	**1.69** **	**2.39*** **	**0.43* **
Crude	**1.32**	**1.11**	**0.28*** **	**2.39**	**0.98**		**0.32**	**0.08*** **	0.02	−0.08	**0.73** **	−1.31
Gold	**0.05**	**0.38**	0.03	**0.43**	**0.35**	**0.40*** **		**0.80*** **	**0.45** **	**0.47** **	**0.57**	**0.43*** **
Natural	**2.38*** **	**3.13**	−0.84**	**4.08*** **	**4.08** **	**1.05**	−0.66*		**0.50**	**2.68*** **	**0.07**	**2.75*** **
Silver	−0.51*	−0.39**	**1.12**	**0.97*** **	−2.34***	**0.46*** **	**0.31*** **	**1.69*** **		−0.06	−0.57	**0.31**
Soybean	**0.60**	**0.30**	**1.41*** **	**1.76** **	**1.75**	**0.65** **	**0.22**	**2.55* **	**1.14*** **		**0.20**	−0.01*

(Continues)

TABLE 7 (Continued)

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equity
Sugar	**0.56*****	−0.41***	−11.99***	**1.62*****	**5.07**	**2.05*****	−13.33	**0.34*****	**0.17*****	−0.47***		−9.51
Equity	−8.61**	−6.31***	−5.43***	−3.09	−3.05	−4.23	−6.82***	−2.69**	−0.20**	−2.07	−2.89***	

Note: In-sample and out-of-sample results for spillover tests for the different components of the volatility term structure are presented. We run the following regression:

$$\mathrm{PC}_{i,t} = \sum_{k=1}^{p} \beta_k^1 \mathrm{PC}_{i,t-k} \cdot I_N + \sum_{k=1}^{p} \beta_k^2 \mathrm{PC}_{i,t-k} \cdot I_T + \sum_{k=1}^{p} \beta_k^3 \mathrm{PC}_{i,t-k} \cdot I_D + \sum_{u=1}^{p} \gamma_u^1 \mathrm{PC}_{j,t-u} \cdot I_N + \sum_{u=1}^{p} \gamma_u^2 \mathrm{PC}_{j,t-u} \cdot I_T + \sum_{u=1}^{p} \gamma_u^3 \mathrm{PC}_{j,t-u} \cdot I_D + \mathrm{VRP}_t + \mathrm{PCE}_t + \epsilon_t.$$

Commodity i (which is affected by the spillovers) is presented in the first column, commodity j (from which the spillovers originate) is presented in the first row. We test the null hypothesis, H_0: $\gamma_u^1 = \gamma_u^2 = \gamma_u^3 = 0$. For in-sample significance, we use a Wald test of the H_0 using Newey and West (1986) standard errors with 10 lags. *, **, and ***, respectively indicate significance for the 10%, 5%, and 1% level, respectively. For out-of-sample tests, we use an expanding window, initialized by 100 observations. We present the out-of-sample $R^2 (R^2 = 1 - \frac{\mathrm{MSE}_{\mathrm{un}}}{\mathrm{MSE}_{\mathrm{re}}})$ in the body of the tables. Significant R^2s based on McCracken (2007) test statistics are printed in bold.

TABLE 8 State-dependent spillovers between markets

	Normal		Tranquil		Distressed	
	Median R^2	Significant obs.	Median R^2	Significant obs.	Median R^2	Significant obs.
Panel A: Level						
Cocoa	0.41	2	0.34	3	0.32	2
Coffee	0.27	3	0.20	3	0.32	1
Copper	0.33	0	0.21	4	0.89	2
Corn	0.59	3	0.28	1	0.76	3
Cotton	0.98	2	0.45	3	1.02	3
Crude	0.60	4	0.43	8	1.09	5
Gold	0.42	2	0.18	3	0.62	3
Natural gas	0.40	1	0.25	4	0.59	1
Silver	0.74	1	0.22	6	1.14	2
Soybeans	0.23	3	0.20	5	0.44	2
Sugar	0.61	1	0.25	3	0.64	3
Equity	0.41	5	0.30	5	0.47	5
Panel B: Slope						
Cocoa	0.28	3	0.16	3	0.19	2
Coffee	0.27	3	0.03	2	0.12	6
Copper	0.17	3	0.06	2	0.31	1
Corn	0.18	3	0.09	5	0.54	4
Cotton	0.14	2	0.03	2	0.35	1
Crude	0.43	2	−0.05	3	0.38	3
Gold	0.30	2	−0.10	3	0.56	1
Natural gas	0.10	3	0.35	8	0.30	2
Silver	0.24	3	0.17	3	0.62	0
Soybeans	0.11	3	0.21	1	0.17	2
Sugar	0.48	3	0.10	3	0.34	4
Equity	0.24	5	0.29	5	0.33	1
Panel C: Curvature						
Coffee	0.08	1	0.17	4	0.18	1
Copper	0.15	0	0.05	3	0.23	2
Corn	0.36	5	0.18	5	0.65	4
Cotton	0.02	2	−0.01	3	0.69	3
Crude	0.12	2	0.01	1	0.49	3
Gold	0.19	2	0.04	1	0.19	0
Natural gas	0.11	4	0	2	0.33	3
Silver	0.12	2	0.14	4	0.47	3
Soybeans	0.06	1	0	3	0.20	2
Sugar	0.07	3	0.03	2	0.38	3
Equity	0.06	1	0.14	9	0.30	1

Note: In-sample and out-of-sample results for spillover tests for the different components of the volatility term structure. We run the following regression:

$$\mathrm{PC}_{i,t} = \sum_{k=1}^{p} \beta_k^1 \mathrm{PC}_{i,t-k} \cdot I_N + \sum_{k=1}^{p} \beta_k^2 \mathrm{PC}_{i,t-k} \cdot I_T + \sum_{k=1}^{p} \beta_k^3 \mathrm{PC}_{i,t-k} \cdot I_D + \sum_{u=1}^{p} \gamma_u^1 \mathrm{PC}_{j,t-u} \cdot I_N + \sum_{u=1}^{p} \gamma_u^2 \mathrm{PC}_{j,t-u} \cdot I_T + \sum_{u=1}^{p} \gamma_u^3 \mathrm{PC}_{j,t-u} \cdot I_D + \mathrm{VRP}_t + \mathrm{PCE}_t + \epsilon_t.$$

We summarize the results for the respective commodities j (from which the spillovers originate) in the first column. We test the null hypothesis, H_0: $\gamma_u^1 = 0$ (H_0: $\gamma_u^2 = 0$, H_0: $\gamma_u^3 = 0$) for normal (tranquil, distressed) periods. For in-sample significance, we use a Wald test of the H_0 using Newey and West (1986) standard errors with 10 lags. For out-of-sample tests, we use an expanding window, initialized by 100 observations. We present the median out-of-sample R^2 for each panel ($R^2 = 1 - \frac{\mathrm{MSE_{un}}}{\mathrm{MSE_{re}}}$) in the body of the tables. We count a significant observation only when both the out-of-sample R^2s based on McCracken (2007) test statistic and the in-sample Wald test with Newey and West (1986) standard errors are significant toward the 10% level.

finding is that the equity market reacts in a more timely manner to the changes in the business cycle. Robe and Wallen (2016) observe a similar linkage between the equity markets and crude oil. We observe lagged information transmission to the business cycle sensitive commodity markets. The spillovers are largest from the equity market in periods of distress and normal periods, which can be seen in Table A3. In tranquil periods there is a feedback effect with the commodity market, indicating that the commodity markets' volatilities mainly influence the equity market in periods of low storage and tight supply, that will likely occur in tranquil periods due to higher demand. For the level factor, spillovers from the equity market decrease during tranquil periods while those to the equity market are somewhat higher than in normal and distressed periods.

The term structure components of copper Granger-cause those of commodities in the same sector, crude oil and the equity market, which are connections we would expect from a business cycle sensitive commodity like copper. Jacobsen, Marshall, and Visaltanachoti (2019) show that metal returns lead equity markets. This connection to the equity market can also be observed for the level of the volatility term structure. We also see substantial spillovers from the gold market. In distress there are significant spillovers from gold to copper and corn. In tranquil periods there are spillovers to cocoa and crude oil and during normal periods to copper. Gold only spills over to silver in all economic states. The spillover to cocoa might be linked to the influence of interest rates that the level of gold captures, as can be seen in Table 4. This transmits to changes in the expected convenience yield, which alters the expected level of inventory and results in changes for the level volatility of cocoa.

Corn and soybeans do not show a lot of sector commonalities for spillovers in level, but both spill over to natural gas and gold. The link to natural gas might have something to do with their role as a fertilizer and as a main energy source for drying crops after the harvest. The larger the volatility, the higher is the incentive to produce more crops to smooth production and deliveries, which results in the use of natural gas to dry crops faster. Cotton captures demand-driven volatility fairly fast and thus spills over to the gold market, especially during tranquil and distressed periods.

Cotton volatility Granger-cause a lot of commodity markets and is, in turn, only Granger caused by the volatility of three markets: crude oil, soybeans, and sugar. Cotton Granger-cause especially natural gas, a link which is not obvious. However, there are several possibilities. First, cotton is a competitor in the clothing industry with synthetic fibers that are produced from natural gas. Second, both commodities are highly sensitive to the weather in the United States, or more particularly in the Midwest, where a majority of the production is located. Third, storms will increase the level for both commodities, introducing supply disruptions to the market. Fourth, heatwaves decrease the harvest estimated for cotton and increase energy demand due to cooling.

Sugar is linked to the softs market. The connection is especially large during distress. One reason for this link might be the strong relationship of sugar to the housing market in level that it shares with the rest of the softs market, for which the link is weaker. The level of sugar also causes the level of crude oil. Both are linked due to biofuel production, where sugar cane is an efficient alternative and Brazil can as a main producer of both ethanol and sugar canes circumvent export restrictions for sugar by exporting ethanol.

The spillovers from crude oil to natural gas are small. This is in line with Bachmeier and Griffin (2006), who find that there exists no common primary energy market. In level the crude oil market spills over to every market. One reason for the high spillover is the influence of institutional investors that invest more heavily in liquid business cycle related markets. An indication for this can also be that crude oil is linked to the metal market in all economic states. Evidence of that phenomenon can be seen in the literature on the financialization of the commodity market. Basak and Pavlova (2016) show in a model that shocks to index commodities spill over to prices and inventories of other index commodities. Due to the influence on prices and inventories on volatility, this will also result in volatility spillovers. Institutional investors can increase those spillovers via an increased correlation.

Volatility slope: Panel B of Table 7 displays the results for the slope. The equity market is less connected to the commodity market, spilling over only to the agricultural market and to precious metals. The slope of the equity volatility term structure cannot capture the unique patterns of the commodity market. A majority of the spillovers occur in tranquil periods, when the economic expansion, that is reflected first in the stock market, leads to higher volatility in prices for the equity market and subsequently the commodity market, as can be seen in Table 8. Short-term volatility increases more strongly, when inventory is tight (Fama & French, 1988). This effect spills over to the equity market from the crude oil market and increases the slope as well, increasing the short-term uncertainty of equity markets.

For the slope, spillovers from the equity market are higher than from the commodity market. Copper, gold, and silver all show spillovers that are lower for the slope compared to the spillovers in level. This might be due to the low informativeness of the term structure for metals compared to the level. The highest amount of spillovers can be seen during tranquil periods, when inventory is low.

Spillovers to the slope of corn are large from coffee and cocoa, which shows short-term macroeconomic information transmission. Coffee spills over to other markets especially during periods of distress, which is an indication that coffee captures macroeconomic information of the slope of the volatility term structure earlier, which influences other commodity markets in such periods. Gold and copper are likely Granger-caused by cotton, because it can capture a variety of general macroeconomic variables that can serve as early indicators for the general economic activity as, for example, wages in the United States. Cotton is a labor-intensive product with a high production share in the United States. Increases or decreases in the wage will quickly be reflected in the volatility of the price and subsequently in the demand for metals, which will affect volatility as well.

For the slope of the term structure, we still see a high degree of spillovers from crude oil to other markets. The spillover to corn for the slope is large during normal periods and in distress. This indicates that the short-term volatility of natural gas has a high influence on the slope of corn, likely because of its use as a fertilizer. Large changes in the price of natural gas can lead to large short-term changes in the price of corn; we have seen before that the same holds for the level, where the effects on the average volatility seem to be stronger for short-term volatilities.

Volatility curvature: The main results for the curvature are in Panel C of Table 7. As can be seen from Table 8, there are significant spillover effects from the equity market to all commodity markets in tranquil market periods. A shock to the term structure of the equity market always spills over to the term structure of the commodity market, but we cannot observe spillover effects from the commodity market to the equity market. For the slope and the curvature of the agricultural market, we observe more spillovers for corn than for soybeans. The reason for this might be that corn captures relatively more macroeconomic variables for the shape of the volatility term structure, while the shape of the term structure of soybeans is idiosyncratic, as can be seen in Tables 5 and 6. Large links to natural gas from the agricultural and softs markets show the medium-term impact of the volatility of agricultural goods on the volatility of natural gas.

Summarizing the results, we see that spillovers are strongly dependent upon economic states. They are strongest during market distress and comparably smallest in normal periods. Furthermore, intra-commodity effects are more important for the commodity market than spillover effects originating from the equity market. Intra-commodity effects rarely spill over to the equity market.

3.4 | Financialization

We now investigate the option-implied volatility term structure with regard to the financialization of the commodity market. To do so, we split our sample into two parts. January 2004 is often regarded as the break point of financialization (Christoffersen et al., 2019; Hamilton & Wu, 2015).[9] In Table 9 we display the correlations pre- and post-financialization. At the bottom of each table we report the correlation of each variable with the first PC of the entire market. We see that the difference between the two periods is stark. In the grey colored post-financialization period the negative correlations disappear entirely compared to the pre-financialization period. Correlations are mostly above 0.4. The correlations of the factors of the term structure of natural gas and coffee with other commodities are much lower—they are outliers in this regard. After financialization, the component is large across commodities and (with the exception of coffee) above 0.5. Investigating the remaining factors of the implied volatility term structure, we see a further integration for the slope factor for the postfinancialization period. For the second subsample the first PC of the market shows consistently positive correlations with every single market, indicating a strong common factor structure (except for natural gas). The correlations are high for the precious metals market, crude oil and the equity market. They are among the most relevant markets for institutional investors and should be the markets that we expect to show the highest degree of financial integration.

The curvature factor also exhibits different correlations in the two sub-samples, but they could be due to changing common factors for the commodity market. One key feature of financialization – a stronger integration with the equity and crude oil market—is not present for the curvature of the volatility term structure. We see especially high correlation for sugar, corn and soybeans, mostly with each other and copper. Sugar also displays high correlations within the softs sector. In summary, we see that the volatility term structure for commodity and equity markets is strongly integrated post-financialization.

With the effects of financialization on the commodity market, there might have been a substantial shift in spillovers. To investigate this, we conduct the spillover analysis separately for the pre- and post-financialization periods in Tables A6 and A7 of the Online Appendix. The test is the same as in Equation (7). We expect two opposing effects of the financialization on spillovers. First, we would expect larger spillovers, because we have more common factors that

[9]This date roughly corresponds with a break point analysis we have conducted. The Chow test detects break points for the volatility term structure for all commodity markets around 2004–2005.

TABLE 9 Correlations—pre- and post-financialization

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equity
Panel A - Level												
Cocoa	1.00	0.24	0.60	0.68	0.63	0.64	0.56	0.41	0.53	0.78	0.68	0.59
Coffee	0.39	1.00	0.15	0.15	0.26	0.26	0.04	0.15	0.10	0.27	0.27	0.09
Copper	−0.24	−0.22	1.00	0.62	0.39	0.64	0.71	0.71	0.67	0.62	0.53	0.57
Corn	0.07	0.05	0.19	1.00	0.70	0.61	0.68	0.30	0.66	0.79	0.69	0.69
Cotton	0.37	0.20	−0.17	0.12	1.00	0.52	0.45	0.07	0.61	0.60	0.69	0.54
Crude	0.57	0.17	−0.31	−0.17	0.55	1.00	0.62	0.44	0.59	0.60	0.52	0.73
Gold	0.70	0.23	−0.32	0.02	0.35	0.52	1.00	0.38	0.87	0.55	0.49	0.79
Natural	0.23	0.17	−0.25	−0.26	0.34	0.47	0.30	1.00	0.32	0.40	0.32	0.19
Silver	0.16	−0.37	0.20	0.05	0.19	−0.06	0.60	−0.28	1.00	0.49	0.55	0.69
Soybean	0.41	0.07	0.19	0.70	0.26	−0.05	0.32	−0.18	0.41	1.00	0.59	0.53
Sugar	0.52	0.17	−0.11	0.09	0.52	0.60	0.50	0.24	−0.12	0.16	1.00	0.53
Equity	0.21	0.01	−0.12	0.03	0.11	0.49	0.31	0.10	−0.23	−0.08	0.54	1.00
Before	−0.04	0.51	−0.25	−0.62	−0.11	0.53	−0.74	0.32	−0.81	−0.81	0.59	0.76
After	0.83	0.28	0.81	0.87	0.73	0.78	0.81	0.52	0.81	0.82	0.79	0.79
Panel B - Slope												
Cocoa	1.00	0.26	0.13	0.26	−0.02	0.18	0.31	−0.02	0.19	0.19	0.14	0.16
Coffee	0.29	1.00	0.08	0.23	0.06	−0.21	0.15	0.21	0.07	0.29	0.36	0.05
Copper	0.10	0.19	1.00	0.12	0.08	0.17	0.24	0.10	0.24	0.11	0.00	0.18
Corn	0.28	0.49	0.09	1.00	0.25	−0.11	0.19	−0.21	−0.01	0.67	0.28	0.12
Cotton	0.18	0.00	−0.03	0.23	1.00	−0.04	−0.03	−0.07	−0.06	0.24	0.23	−0.04
Crude	0.06	−0.11	0.25	−0.28	−0.16	1.00	0.43	−0.00	0.45	−0.06	−0.11	0.35
Gold	−0.10	0.09	−0.18	0.15	0.05	−0.02	1.00	−0.09	0.72	0.14	0.09	0.69
Natural	0.24	0.15	−0.07	−0.01	0.08	0.09	0.05	1.00	0.00	−0.06	−0.12	−0.14
Silver	−0.21	−0.10	−0.03	−0.17	−0.30	-0.02	0.29	−0.01	1.00	−0.00	0.08	0.48
Soybean	0.21	0.43	0.15	0.71	0.33	-0.27	0.16	0.01	−0.03	1.00	0.27	0.08
Sugar	0.06	0.16	0.14	0.01	0.04	-0.05	0.22	0.17	0.33	0.10	1.00	−0.03
Equity	0.17	−0.09	0.13	−0.08	−0.04	0.29	−0.08	0.16	−0.09	−0.21	−0.22	1.00
Before	0.29	0.31	0.22	0.64	0.63	−0.47	0.29	0.33	0.12	0.77	0.64	−0.08
After	0.43	0.11	0.34	0.34	0.05	0.62	0.89	−0.18	0.75	0.26	0.20	0.75
Panel C - Curvature												
Cocoa	1.00	0.60	0.36	−0.62	−0.37	−0.03	0.01	−0.31	0.21	−0.08	0.77	−0.01
Coffee	0.25	1.00	0.29	−0.50	−0.41	−0.17	0.02	−0.07	0.22	−0.20	0.62	0.07
Copper	0.31	−0.12	1.00	−0.35	−0.21	−0.04	−0.13	−0.09	0.08	−0.14	0.38	0.03
Corn	−0.54	0.20	−0.43	1.00	0.44	0.02	0.13	0.31	−0.08	0.35	−0.61	−0.04
Cotton	−0.19	0.10	−0.11	0.27	1.00	0.18	0.04	0.21	−0.22	0.39	−0.48	−0.09
Crude	0.28	0.22	0.19	−0.22	0.01	1.00	−0.03	−0.12	−0.13	0.12	−0.01	−0.19
Gold	0.07	0.13	0.03	0.06	−0.07	−0.01	1.00	0.19	0.08	0.06	−0.13	0.23
Natural	0.24	0.19	−0.13	−0.32	−0.11	0.04	0.17	1.00	0.07	−0.05	−0.39	0.16
Silver	0.41	0.08	0.11	−0.38	0.03	0.18	0.01	0.34	1.00	−0.05	0.17	0.08
Soybean	−0.50	0.11	−0.16	0.74	0.28	−0.06	0.03	−0.30	−0.35	1.00	−0.22	−0.10
Sugar	0.53	−0.01	0.30	−0.65	−0.35	0.21	0.04	0.32	0.46	−0.58	1.00	−0.12
Equity	0.05	0.16	−0.04	0.00	0.03	0.12	0.03	0.10	0.04	0.03	0.05	1.00
Before	0.89	0.41	0.34	−0.89	−0.12	0.45	0.19	0.68	0.56	−0.81	0.84	0.17
After	0.85	0.77	0.52	−0.79	−0.68	−0.14	−0.11	−0.43	0.31	−0.37	0.87	0.02

Note: The correlations, for the post-financialization (starting from Jan 01, 2004; in the top right in grey) and pre-financialization (before Jan 01, 2004; in the bottom left) periods. Before indicates the correlation of the PCs with the first PC of the respective factor over all commodity markets pre-financialization. After is the same measure for the post-financialization period.

influence the commodity markets. Second, we would, on the other hand, expect lower spillovers, because more changes will occur contemporaneously, as the correlations in Table 9 indicate. In Table A7 for the post-financialization period we see that almost all out-of-sample R^2s are positive, while in Table A6 for the pre-financialization period, part of the coefficients are negative. The in-sample Wald test indicates stronger significance for the post-financialization period, which could just be a result of the lower power for the pre-financialization period. Post-financialization, the spillovers are more consistent across commodities and spillovers for the level from and to the equity market are larger than pre-financialization. However, for the level, spillovers within the commodity market decrease. This indicates, in combination with the correlations in Table 9, that due to similar investor groups and similar behavior, we see more contemporaneous movements of the commodity market and less lagged dependence. For spillovers in the slope and the curvature of the commodity term structure, we see that they actually increase after financialization. Those factors seem to be more influenced by short-term movements. The increase in common factors leads to more spillovers across commodity markets. We conclude that there are two effects that affect spillovers pre- and postfinancialization: the increase in contemporaneous movements lowers spillovers for the level. For the slope and the curvature, the increase in common factors leads to higher spillovers overall.

3.5 | Macroeconomic announcements

A potential cause of the spillovers is information transmission. One commodity market will capture the macroeconomic or commodity-specific information earlier, which impacts the volatility term structure of other markets with a lag. A natural economic experiment is the investigation of scheduled macroeconomic news announcements. Savor and Wilson (2013, p. 343) state: "Investors do not know what the news will be, but they do know that there will be news. If asset prices respond to these news, the risk associated with holding the affected securities will be higher around announcements." If spillovers are larger following news announcements, then it is likely that one commodity market captures the information of the news first and this information will subsequently spill over to the other markets. Macroeconomic news announcements have been evaluated in the literature. Lucca and Moench (2015) find that the returns before scheduled news announcements are larger. Most recently, Wachter and Zhu (2018) find that the relation between market betas and expected returns are far stronger on announcement days.

To investigate the influence of information transmission on spillovers, we analyze the influence of scheduled macroeconomic news. We estimate the following regression:

$$\begin{aligned} \mathrm{PC}_{i,t} = a &+ \sum_{k=1}^{p}\beta_k^1 \mathrm{PC}_{i,t-k} I_N + \sum_{k=1}^{p}\beta_k^2 \mathrm{PC}_{i,t-k} I_T + \sum_{k=1}^{p}\beta_k^3 \mathrm{PC}_{i,t-k} I_D \\ &+ \sum_{u=1}^{p}\gamma_u^1 \mathrm{PC}_{j,t-u} I_N + \sum_{u=1}^{p}\gamma_u^2 \mathrm{PC}_{j,t-u} I_T + \sum_{u=1}^{p}\gamma_u^3 \mathrm{PC}_{j,t-u} I_D \\ &+ \sum_{l=1}^{p}\tau_l^1 \mathrm{PC}_{j,t-l} I_N I_{\mathrm{Ann}} + \sum_{l=1}^{p}\tau_l^2 \mathrm{PC}_{j,t-l} I_T I_{\mathrm{Ann}} + \sum_{l=1}^{p}\tau_l^3 \mathrm{PC}_{j,t-l} I_D I_{\mathrm{Ann}} + \epsilon_t. \end{aligned} \tag{9}$$

$\mathrm{PC}_{i,t}$ represents a PC of commodity i and $\mathrm{PC}_{j,t}$ the PC of commodity j at time t. I_{Ann} is 1 when we have an announcement date. We test the null hypothesis of: $\tau_j^1 = \tau_j^2 = \tau_j^3 = 0$. If the Wald test is significant, scheduled macroeconomic news will affect the spillover from the day of the announcement. To investigate how large the contribution of macroeconomic news announcements is, we decompose the R^2 using the method by Lindeman, Merenda, and Gold (1980). This measure uses a simple unweighted average of average contributions of different models of different sizes. The measure sums up to the original R^2.

We use the following macroeconomic news announcement categories: Employment (E), Consumer Confidence (CC), CPI (CPI), Durable (D), Factory Orders (FO), Federal Funds Rate (FFR), GDP (GDP), Housing (H), Industrial production (IP), Initial Jobless Claims (IJC), International Trade (IT), ISM Manufacturing PMI (ISM-M), ISM N-Mfg PMI (ISM N-M), Retail Sales (RS), and Michigan Consumer Sentiment (M).

Table A8 of the Online Appendix shows the summary statistics of the macroeconomic announcements. We find the percentage overlap for announcement observations is overall modest. This is relevant, particularly because a large overlap of announcement makes it impossible to separate the impact between the impact of those events. For example, factory orders and the employment situation report are reported on the same day 16% of the time. For only few announcement pairs this share is higher, and for the vast majority it is substantially lower.

Tables 10 and 11 report the significant macroeconomic spillovers at the 10% level with Newey and West (1986) standard errors. Table 10 shows how many scheduled macroeconomic news events are significant for any commodity pair. Table 11 shows which macroeconomic news yield spillovers for the different commodities. The numbers indicate how many observations are significant in-and out-of-sample. In the parentheses below the maximum (Table 10) or median (Table 11) additional R^2 relative to the total R^2 explained by spillovers is reported. We choose the maximum

TABLE 10 Information transmission—news announcements

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equities
Panel A: Level												
Cocoa		6 (13.62)	6 (54.53)	5 (29.01)	6 (30.52)	4 (21.42)	8 (20.81)	3 (46.20)	3 (17.46)	2 (30.01)	2 (12.16)	3 (29.44)
Coffee	4 (13.23)		6 (40.52)	9 (27.61)	7 (45.45)	7 (32.55)	7 (43.04)	4 (15.57)	4 (6.35)	5 (71.55)	5 (27.65)	8 (34.31)
Copper	3 (38.47)	2 (50.74)		1 (25.51)	8 (23.97)	3 (25.92)	5 (25.19)	5 (26.72)	5 (25.27)	3 (30.35)	0 (18.16)	6 (33.41)
Corn	6 (25.65)	5 (53.50)	5 (24.85)		6 (26.13)	6 (20.29)	7 (24.60)	6 (28.88)	7 (25.38)	7 (29.27)	9 (31.02)	4 (24.62)
Cotton	5 (30.78)	5 (54.99)	5 (24.47)	4 (43.48)		8 (24.09)	5 (24.63)	1 (44.18)	5 (40.99)	4 (38.30)	1 (36.79)	7 (27.28)
Crude	3 (20.56)	1 (67.24)	2 (34.34)	5 (20.53)	9 (29.52)		6 (19.07)	5 (38.75)	6 (26.35)	4 (7.29)	3 (29.22)	8 (26.81)
Gold	4 (21.25)	6 (24.20)	7 (25.36)	7 (24.56)	6 (25.19)	6 (20.27)		5 (21.61)	7 (20.75)	3 (10.52)	6 (23.96)	9 (24.44)
Natural	2 (46.65)	1 (22.93)	5 (48.38)	5 (38.80)	3 (57.73)	7 (31.42)	4 (23.06)		6 (18.53)	0 (19.42)	3 (40.21)	6 (50.99)
Silver	4 (10.95)	1 (7.73)	5 (25.41)	4 (25.17)	4 (24.81)	9 (24.45)	3 (20.07)	3 (10.82)		2 (5.81)	1 (6.55)	6 (27.19)
Soybean	3 (18.72)	4 (62.66)	5 (28.12)	4 (25.43)	7 (25.70)	4 (5.89)	4 (10.46)	5 (15.30)	4 (5.79)		2 (13.92)	6 (17.29)
Sugar	4 (20.21)	8 (44.64)	7 (40.13)	9 (54.50)	12 (44.59)	5 (28.21)	8 (37.24)	7 (47.43)	3 (20.45)	4 (28.78)		8 (36.48)
Equities	5 (25.44)	4 (33.98)	5 (25.16)	3 (24.94)	6 (25.25)	4 (25.64)	9 (24.69)	0 (33.45)	8 (22.99)	1 (16.71)	6 (26.47)	
Panel B: Slope												
Cocoa		4 (29.13)	5 (64.64)	5 (28.12)	6 (64.52)	8 (72.10)	6 (61.00)	10 (32.70)	8 (60.95)	6 (34.69)	4 (40.59)	9 (31.18)
Coffee	3 (24.74)		4 (26.46)	8 (25.09)	9 (38.03)	5 (34.16)	9 (37.45)	11 (29.37)	5 (52.14)	2 (23.29)	12 (25.87)	8 (52.57)
Copper	9 (45.62)	3 (37.50)		3 (60.01)	4 (37.54)	3 (29.42)	5 (34.13)	6 (39.98)	1 (25.38)	8 (53.31)	6 (27.89)	9 (40.56)
Corn	6 (31.27)	6 (26.73)	8 (48.32)		8 (24.62)	4 (43.81)	10 (26.09)	6 (52.72)	6 (42.13)	9 (24.60)	9 (25.98)	11 (41.91)
Cotton	12 (57.24)	3 (31.99)	5 (40.15)	1 (26.04)		4 (77.84)	5 (56.77)	6 (50.66)	8 (76.24)	2 (11.19)	9 (36.03)	8 (67.62)
Crude	7 (50.40)	5 (30.33)	5 (33.50)	8 (48.90)	6 (58.88)		7 (51.75)	8 (51.01)	8 (31.78)	6 (40.23)	5 (37.68)	12 (46.82)
Gold	6 (44.38)	5 (22.70)	9 (42.58)	7 (33.30)	9 (54.93)	11 (61.09)		4 (29.61)	10 (24.89)	5 (26.98)	11 (26.19)	14 (47.03)
Natural	4 (36.34)	6 (28.09)	4 (42.27)	9 (57.46)	2 (39.49)	10 (57.63)	4 (43.36)		8 (32.72)	7 (35.63)	0 (41.74)	5 (42.03)
Silver	7 (53.40)	7 (46.82)	12 (29.06)	5 (50.95)	6 (68.03)	10 (48.55)	8 (30.71)	5 (32.38)		5 (57.25)	7 (27.06)	12 (40.16)
Soybean	8 (43.86)	10 (20.99)	5 (48.35)	7 (24.51)	7 (12.94)	6 (26.34)	3 (31.77)	6 (29.71)	7 (74.76)		11 (29.30)	10 (53.87)
Sugar	8 (61.60)	6 (26.96)	8 (28.79)	8 (25.49)	6 (31.36)	6 (41.18)	9 (25.68)	7 (42.58)	14 (28.07)	8 (33.03)		7 (39.98)
Equities	3 (33.38)	3 (39.12)	10 (49.44)	4 (48.44)	4 (64.41)	8 (53.31)	8 (45.88)	6 (52.84)	13 (36.27)	2 (70.78)	6 (51.17)	
Panel C: Curvature												
Cocoa		13 (28.74)	8 (27.69)	8 (28.66)	1 (38.69)	10 (33.52)	5 (57.80)	13 (74.14)	4 (27.41)	9 (27.31)	2 (26.21)	10 (66.72)

(Continues)

TABLE 10 (Continued)

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equities
Coffee	10 (34.03)		9 (82.08)	3 (72.95)	6 (65.13)	11 (45.17)	4 (54.62)	9 (57.82)	7 (32.49)	10 (35.45)	3 (46.45)	10 (57.71)
Copper	5 (25.52)	4 (73.18)		4 (23.20)	5 (27.30)	6 (61.06)	6 (52.52)	8 (52.34)	4 (38.75)	9 (32.31)	3 (29.05)	7 (43.24)
Corn	6 (25.22)	3 (50.16)	6 (25.16)		5 (17.68)	6 (87.30)	5 (35.18)	9 (71.63)	10 (20.81)	5 (22.32)	6 (25.90)	7 (42.88)
Cotton	5 (47.79)	5 (23.94)	7 (33.48)	7 (17.73)		8 (65.22)	4 (24.30)	5 (73.59)	1 (29.74)	2 (16.92)	4 (23.22)	7 (54.80)
Crude	3 (39.96)	5 (31.18)	1 (65.78)	5 (55.40)	1 (34.64)		3 (29.11)	8 (43.81)	4 (62.14)	5 (70.42)	4 (51.84)	9 (68.85)
Gold	6 (51.19)	3 (76.88)	3 (60.64)	3 (31.25)	4 (34.93)	9 (87.36)		9 (51.60)	6 (44.42)	3 (50.09)	5 (39.99)	9 (66.83)
Natural	7 (74.88)	1 (46.24)	2 (34.52)	8 (40.33)	4 (44.87)	7 (48.00)	3 (40.72)		6 (40.07)	1 (32.39)	1 (51.32)	7 (36.72)
Silver	4 (28.45)	8 (26.44)	9 (38.25)	7 (25.98)	4 (33.45)	8 (88.36)	7 (36.23)	7 (58.32)		9 (43.85)	4 (38.22)	11 (45.39)
Soybean	4 (21.23)	7 (26.66)	8 (22.74)	9 (22.19)	3 (15.60)	6 (43.93)	5 (27.51)	5 (24.02)	9 (37.82)		3 (27.60)	9 (51.28)
Sugar	4 (30.85)	4 (62.04)	5 (38.85)	10 (24.03)	6 (22.97)	8 (41.35)	8 (37.31)	6 (63.57)	12 (29.03)	10 (31.35)		9 (83.37)
Equities	2 (73.89)	4 (64.73)	1 (51.68)	3 (71.53)	5 (69.64)	7 (87.99)	4 (48.37)	2 (55.57)	8 (42.59)	5 (68.32)	1 (74.43)	

Note: This table displays the number of significant macroeconomic variables. The influence is estimated with a Wald test based on the following regression:

$$\begin{aligned}\mathrm{PC}_t^{(k)} = a &+ \sum_{j=1}^{p}\beta_j^1 \mathrm{PC}_{t-j}^{(k)} I_N + \sum_{j=1}^{p}\beta_j^2 \mathrm{PC}_{t-j}^{(k)} I_T + \sum_{j=1}^{p}\beta_j^3 \mathrm{PC}_{t-j}^{(k)} I_D \\ &+ \sum_{j=1}^{p}\gamma_j^1 \mathrm{PC}_{t-j}^{(l)} I_N + \sum_{j=1}^{p}\gamma_j^2 \mathrm{PC}_{t-j}^{(l)} I_T + \sum_{j=1}^{p}\gamma_j^3 \mathrm{PC}_{t-j}^{(l)} I_D \\ &+ \sum_{j=1}^{p}\tau_j^1 \mathrm{PC}_{t-j}^{(l)} I_N I_{\mathrm{Ann}} + \sum_{j=1}^{p}\tau_j^2 \mathrm{PC}_{t-j}^{(l)} I_T I_{\mathrm{Ann}} + \sum_{j=1}^{p}\tau_j^3 \mathrm{PC}_{t-j}^{(l)} I_D I_{\mathrm{Ann}} + \epsilon_t.\end{aligned}$$

Commodity i (which is affected by the spillovers) is presented in the first column, commodity j (from which the spillovers originate) is presented in the first row. We test the null hypothesis, of $\tau_j^1 = \tau_j^2 = \tau_j^3 = 0$. For each commodity pair, we count the number of macroeconomic news series that yield a significant Wald test at 10%. We use Newey and West (1986) standard errors with 10 lags. Panels A–C represent the values for various PCs. In parentheses we display the result of a decomposition of the R^2 (in %). The method was introduced by Lindeman et al. (1980). We use the maximum R^2 of spillovers after macroeconomic news announcements relative to the R^2's from spillovers overall.

relative R^2 because it is more important to have an idea how much additional explanatory power the most important macroeconomic news announcements have for each commodity pair. This is still a conservative estimate of the overall influence of scheduled news events, because there are several different announcement types that create these spillovers. To get an idea how large the influence of each scheduled news announcement is, while avoiding any large observations distorting the reported results, we report the median in Table 11.

We find that spillovers are vastly enhanced for news announcement days. For the level, macroeconomic announcement days are responsible for up to 70% of the total R^2 of all spillovers. Most commodity pairs have at least one macroeconomic news event accounts for at least 15% of the spillovers for the level of the volatility term structure. The share is significantly larger for the slope and the curvature, where macroeconomic news account mostly for at least above 25% of the spillovers. This is because the slope and curvature are influenced more strongly by short-term movements.

In Table 11 we show which macroeconomic events trigger spillovers in the volatility term structure of commodities. In this table, we see the dominant effect of the initial jobless claims report, that seems to introduce increases in spillover effects throughout the commodity market. We find that most important for the commodity market are news

TABLE 11 Information transmission—news

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equities
Panel A: Level												
E	4 (10.54)	3 (12.06)	6 (12.99)	4 (13.85)	7 (12.54)	4 (11.82)	6 (12.17)	4 (12.18)	2 (10.91)	1 (7.00)	5 (13.25)	3 (13.38)
CC	2 (13.10)	3 (14.09)	5 (15.93)	3 (14.76)	7 (14.87)	1 (13.16)	4 (13.25)	4 (12.39)	7 (11.64)	1 (6.30)	2 (13.23)	6 (15.32)
CPI	5 (11.92)	3 (11.55)	4 (13.83)	4 (13.68)	4 (13.66)	5 (12.36)	4 (11.10)	2 (11.57)	4 (11.53)	7 (6.24)	1 (10.44)	3 (14.39)
D	1 (11.56)	4 (12.67)	4 (14.25)	6 (13.87)	4 (13.12)	4 (12.03)	5 (11.81)	1 (10.57)	6 (11.58)	1 (5.62)	1 (14.25)	7 (14.54)
FO	3 (12.25)	0 (12.19)	5 (14.48)	4 (13.55)	8 (13.84)	4 (12.75)	5 (12.41)	2 (13.20)	3 (11.44)	2 (6.55)	6 (13.62)	4 (13.63)
FFR	2 (10.31)	4 (13.14)	6 (13.84)	3 (13.77)	6 (15.62)	7 (12.37)	4 (12.29)	4 (10.73)	6 (11.78)	2 (7.35)	2 (10.06)	3 (12.58)
GDP	1 (10.67)	4 (13.86)	1 (14.32)	1 (14.07)	3 (15.06)	4 (13.12)	4 (12.99)	3 (13.37)	3 (11.22)	1 (7.68)	2 (14.12)	4 (15.23)
H	3 (20.56)	2 (21.66)	2 (24.15)	2 (23.32)	4 (22.90)	2 (22.38)	5 (22.48)	2 (20.63)	4 (19.90)	1 (11.01)	1 (21.75)	7 (24.44)
IP	2 (11.63)	3 (9.91)	2 (13.35)	0 (13.05)	5 (13.86)	2 (12.21)	4 (11.70)	3 (12.23)	2 (11.46)	1 (6.32)	1 (10.76)	2 (13.89)
IJC	7 (19.85)	2 (44.64)	7 (28.12)	8 (20.53)	7 (26.13)	8 (19.45)	3 (15.15)	8 (28.88)	3 (18.53)	5 (28.78)	7 (24.67)	8 (27.28)
IT	2 (11.59)	3 (11.63)	4 (12.11)	4 (13.94)	4 (13.88)	4 (12.74)	6 (11.74)	1 (12.60)	7 (11.71)	4 (6.08)	1 (11.97)	4 (14.06)
ISM-M	4 (14.51)	3 (13.48)	4 (14.67)	6 (15.08)	6 (15.66)	5 (13.03)	3 (14.14)	3 (13.43)	4 (12.12)	3 (6.37)	3 (14.00)	5 (16.00)
ISM-N-M	2 (13.02)	2 (11.67)	5 (14.85)	7 (14.13)	6 (14.37)	5 (13.15)	6 (14.16)	0 (14.13)	2 (11.81)	2 (6.90)	2 (14.07)	7 (14.11)
RS	1 (11.25)	4 (14.23)	1 (12.47)	0 (13.08)	1 (13.70)	2 (12.57)	1 (11.57)	4 (12.57)	1 (11.43)	0 (8.58)	2 (10.96)	2 (13.76)
M	4 (21.25)	3 (20.78)	2 (24.62)	4 (24.94)	2 (25.19)	6 (21.14)	6 (22.91)	3 (20.49)	4 (20.75)	4 (11.09)	2 (23.32)	6 (24.01)
Panel B: Slope												
E	8 (21.62)	4 (14.08)	3 (21.53)	4 (16.27)	3 (21.99)	4 (17.94)	6 (17.48)	2 (24.22)	9 (19.79)	3 (16.78)	5 (15.52)	8 (12.01)
CC	2 (24.86)	4 (16.51)	4 (18.20)	4 (13.78)	7 (18.99)	6 (15.83)	4 (14.92)	7 (20.78)	7 (17.20)	4 (8.79)	6 (15.24)	6 (14.84)
CPI	3 (19.90)	3 (13.95)	5 (16.40)	5 (15.88)	0 (16.84)	6 (16.81)	4 (16.35)	6 (18.87)	2 (15.19)	4 (12.76)	5 (13.62)	7 (19.32)
D	6 (16.20)	5 (15.83)	6 (17.59)	7 (14.18)	7 (24.21)	4 (15.71)	10 (14.39)	8 (21.31)	8 (16.03)	6 (12.95)	5 (15.41)	6 (18.69)
FO	8 (18.11)	4 (16.82)	4 (20.64)	6 (17.55)	9 (16.65)	4 (14.56)	6 (18.72)	7 (12.70)	9 (16.88)	4 (13.59)	8 (18.93)	4 (14.20)
FFR	9 (12.54)	3 (12.03)	5 (16.36)	3 (12.52)	6 (16.92)	5 (18.78)	5 (14.85)	3 (19.16)	8 (26.40)	7 (16.28)	7 (16.72)	10 (24.10)
GDP	8 (13.53)	6 (12.36)	7 (19.77)	4 (16.25)	4 (27.57)	5 (13.14)	6 (14.47)	4 (13.33)	7 (18.57)	1 (9.37)	5 (15.97)	9 (14.95)
H	2 (24.76)	2 (25.87)	0 (23.49)	3 (25.49)	1 (30.30)	3 (26.69)	3 (24.42)	6 (27.28)	6 (24.18)	1 (18.11)	6 (23.78)	6 (25.94)
IP	2 (21.70)	4 (14.83)	5 (14.55)	5 (15.40)	3 (18.97)	6 (17.22)	5 (15.59)	6 (16.55)	3 (15.55)	3 (19.68)	4 (17.10)	10 (18.96)
IJC	6 (43.86)	5 (26.96)	10 (39.97)	6 (33.30)	4 (23.93)	10 (48.55)	9 (30.71)	4 (32.70)	7 (31.78)	3 (33.03)	3 (23.45)	9 (40.56)

(Continues)

TABLE 11 (Continued)

	Cocoa	Coffee	Copper	Corn	Cotton	Crude	Gold	Natural	Silver	Soybean	Sugar	Equities
IT	2 (15.19)	5 (12.26)	4 (13.57)	4 (17.38)	4 (22.10)	5 (16.79)	2 (18.14)	6 (18.46)	2 (17.89)	8 (14.33)	5 (16.93)	7 (15.29)
ISM-M	6 (14.10)	2 (14.65)	3 (18.03)	4 (17.57)	4 (23.98)	5 (16.52)	5 (18.86)	6 (17.75)	7 (25.47)	3 (14.66)	8 (17.95)	5 (18.18)
ISM-N-M	5 (20.30)	5 (16.43)	6 (20.23)	3 (17.12)	4 (16.32)	7 (15.25)	3 (17.95)	5 (16.65)	6 (18.26)	3 (18.29)	4 (17.78)	6 (11.97)
RS	2 (23.31)	3 (15.45)	7 (14.36)	5 (14.92)	5 (27.66)	2 (16.39)	3 (16.47)	4 (18.86)	3 (18.04)	6 (14.19)	5 (14.58)	8 (17.54)
M	4 (25.82)	3 (22.03)	6 (24.06)	2 (25.09)	6 (29.82)	3 (25.56)	3 (27.32)	1 (29.37)	4 (26.23)	4 (21.94)	4 (24.85)	4 (24.54)
Panel C: Curvature												
E	3 (14.20)	3 (14.19)	6 (15.35)	6 (13.35)	2 (12.53)	10 (19.97)	5 (14.15)	5 (17.24)	4 (17.33)	3 (11.17)	4 (14.12)	8 (20.18)
CC	4 (14.96)	4 (16.25)	2 (16.65)	4 (14.22)	4 (12.49)	5 (19.40)	0 (13.96)	6 (15.40)	5 (16.01)	5 (12.23)	4 (14.44)	8 (17.23)
CPI	5 (13.88)	4 (14.07)	6 (15.19)	2 (14.57)	2 (13.22)	4 (16.19)	1 (17.29)	5 (14.51)	6 (14.57)	5 (16.51)	2 (13.30)	7 (26.56)
D	5 (15.31)	3 (10.76)	7 (18.95)	5 (14.71)	4 (11.91)	6 (18.73)	5 (17.34)	7 (13.32)	8 (13.21)	5 (15.76)	4 (13.40)	9 (18.18)
FO	3 (15.20)	4 (16.23)	6 (19.56)	4 (13.04)	7 (14.23)	6 (24.47)	6 (13.98)	5 (16.07)	7 (18.01)	2 (9.43)	2 (14.94)	8 (21.99)
FFR	6 (10.70)	4 (10.60)	4 (18.03)	7 (12.64)	4 (7.69)	6 (25.20)	2 (16.45)	3 (15.20)	4 (13.69)	5 (13.57)	3 (11.35)	7 (18.06)
GDP	5 (14.61)	5 (14.25)	7 (15.38)	8 (10.09)	2 (11.00)	4 (19.29)	4 (18.85)	7 (15.42)	4 (16.79)	6 (17.04)	3 (12.59)	7 (17.50)
H	2 (25.63)	2 (25.76)	1 (27.69)	3 (25.98)	3 (23.06)	7 (26.51)	2 (24.30)	4 (24.48)	3 (20.94)	5 (30.24)	1 (25.90)	2 (23.75)
IP	4 (13.98)	3 (17.29)	3 (18.17)	4 (15.55)	2 (13.64)	6 (24.12)	3 (21.59)	3 (17.43)	3 (18.69)	6 (21.35)	1 (16.83)	2 (30.19)
IJC	2 (30.85)	7 (46.24)	3 (33.48)	7 (21.71)	5 (33.45)	9 (61.06)	5 (26.78)	6 (57.82)	3 (32.35)	5 (12.87)	5 (29.05)	7 (51.28)
IT	5 (15.23)	6 (17.60)	4 (19.69)	4 (15.45)	2 (15.24)	5 (24.43)	5 (20.61)	6 (16.67)	7 (15.94)	6 (17.52)	0 (13.71)	8 (22.55)
ISM-M	3 (13.27)	3 (14.96)	4 (14.98)	2 (14.54)	2 (13.87)	1 (24.94)	3 (23.46)	8 (20.65)	4 (14.07)	3 (14.31)	3 (14.48)	4 (16.47)
ISM-N-M	2 (14.16)	2 (16.03)	2 (17.27)	3 (15.29)	4 (12.57)	8 (20.59)	8 (27.57)	4 (19.08)	5 (15.81)	1 (11.34)	2 (14.36)	6 (26.75)
RS	2 (16.17)	5 (18.38)	3 (18.96)	3 (17.76)	0 (15.46)	4 (24.59)	2 (19.97)	5 (20.08)	4 (16.84)	5 (20.67)	1 (15.91)	7 (25.71)
M	5 (22.37)	2 (22.26)	1 (25.16)	5 (23.20)	1 (21.06)	5 (26.81)	3 (25.14)	7 (22.92)	4 (23.10)	6 (24.80)	1 (24.18)	5 (26.56)

Note: The number of significant commodities that are influenced by the commodities of the horizontal axis are shown. The influence is estimated with a Wald test based on the following regression:

$$\begin{aligned} \mathrm{PC}_{i,t} = a &+ \sum_{k=1}^{p}\beta_k^1 \mathrm{PC}_{i,t-k} I_N + \sum_{k=1}^{p}\beta_k^2 \mathrm{PC}_{i,t-k} I_T + \sum_{k=1}^{p}\beta_k^3 \mathrm{PC}_{i,t-k} I_D \\ &+ \sum_{u=1}^{p}\gamma_u^1 \mathrm{PC}_{j,t-u} I_N + \sum_{u=1}^{p}\gamma_u^2 \mathrm{PC}_{j,t-u} I_T + \sum_{u=1}^{p}\gamma_u^3 \mathrm{PC}_{j,t-u} I_D \\ &+ \sum_{l=1}^{p}\tau_l^1 \mathrm{PC}_{j,t-l} I_N I_{\mathrm{Ann}} + \sum_{l=1}^{p}\tau_l^2 \mathrm{PC}_{j,t-l} I_T I_{\mathrm{Ann}} + \sum_{l=1}^{p}\tau_l^3 \mathrm{PC}_{j,t-l} I_D I_{\mathrm{Ann}} + \epsilon_t. \end{aligned}$$

We test the null hypothesis, of $\tau_j^1 = \tau_j^2 = \tau_j^3 = 0$. For each commodity pair, we count the number of macroeconomic news series that yield a significant Wald test at the 10% level. We use Newey and West (1986) standard errors with 10 lags. In parentheses we display the result of a decomposition of the R^2. We use the median R^2 of spillovers after macroeconomic news announcements relative to the R^2 from spillovers overall (in %). The method was introduced by Lindeman et al. (1980). Panels A–C represent the values for various PCs. The abbreviations are presented in Section 3.5.

announcements that influence consumer sentiment or income directly, for example, the Michigan Consumer Sentiment Index, or housing sales. All markets show substantial increases in spillovers for certain macroeconomic news announcements. The same holds for the slope and the curvature.

To summarize, we find that macroeconomic news announcements induce a substantial amount of spillovers. There this is thus evidence of information transmission in commodity markets. Moreover, news announcements associated with consumer income or sentiment have a particularly large influence on spillovers for the entire term structure.

4 | ROBUSTNESS

In this section, we examine the robustness of our findings. We change several specifications. First, we also conduct the main analysis with the SVIX by Martin (2017), the summary table is presented in Table A9 of the Online Appendix. The author claims that the SVIX is the true measure of variance, while the VIX is a risk-neutral measure of entropy. The SVIX and the VIX differ by the weighting scheme imposed on the different option prices. The SVIX^2 is described as:

$$\text{SVIX}_t^2 = \frac{2R_t^f}{(T-t)F_{t,T}^2}\left[\int_0^{F_{t,T}} \mathrm{p}_{t,T}(K)dK + \int_{F_{t,T}}^{\infty} \mathrm{c}_{t,T}(K)dK\right].$$

The results for the SVIX, presented in Table A10 of the Online Appendix, show a more consistently positive dependence between commodity markets than for the VIX. This underlines its interpretation as the variance, while the VIX might overweigh the negative tails. This probably leads to more erratic movements in the term structure of the VIX, compared to that of the SVIX, which enables us to uncover even more spillovers. The dynamics are, however, similar compared to the dynamics observed for the VIX. Our main conclusions remain unchanged.

Second, we define the PCs not via an eigenvalue decomposition but parametrically. Aligning with the representation of each component, we use for the first PC the average over all maturities. For the second PC we use the difference between the short-term volatility and the long-term volatility and for the third PC we use the difference between the medium volatility and the short- and long-term volatility:

$$\begin{aligned}
\text{PC}_1 &= \frac{1}{6}(\text{VIX}_1 + \text{VIX}_2 + \text{VIX}_3 + \text{VIX}_6 + \text{VIX}_9 + \text{VIX}_{12}),\\
\text{PC}_2 &= \text{VIX}_1 - \text{VIX}_{12},\\
\text{PC}_3 &= -\text{VIX}_1 + 2\text{VIX}_6 - \text{VIX}_{12}.
\end{aligned}$$

For the parametric specification of the PCs in Table A11 of the Online Appendix, we obtain very similar results. The dynamics differ more for higher order components, for which the correlation decreases. This behavior is to be expected due to the high correlation between both specifications, of an average over 95% for the first component, 85% for the second component and 60% for the third PC.

Finally, we change the estimation level of the VaR from 5% to 1%. The results are in Table A12 of the Online Appendix. Changing the VaR from 5% to the 1% results in different periods being defined as distress, tranquil, and normal periods. In periods when the entire commodity market has been under large distress, the VaR will be high only for the most extreme tail events. With the new definition of the VaR, the new time series shows an estimate of the 1% most extreme events and the dummy variables change slightly. But the change does not alter the previous results of the spillover effects. In particular for the level, the results are very similar. For the slope and the curvature, a change in the dummy variables has a larger effect, however, the results are still qualitatively similar.

5 | CONCLUSION

Investigating the term structure of option-implied volatilities, we address the following questions: What are the macroeconomic determinants of the volatility term structure? How high is the interdependence in the commodity markets, and why is there interdependence? How has the volatility term structure changed due to financialization?

We uncover several results. Macroeconomic variables are an important determinant, in particular for the level of the volatility term structure: speculation and employment influence the level the most. We also show that it is important to consider the cross-sectional variation of commodity markets when aiming to predict future volatility. Observing the rich dynamics of the volatility term structure reveals the benefit of studying the entire volatility term structure. Financialization has led to an increase in contemporaneous movement, which leads to a decrease in long-term spillovers. Spillovers of a short-term nature increase due to the larger number of common factors. Finally, we find that spillovers can, to a large extent, be ascribed to information transmission. Spillovers are substantially stronger when related to macroeconomic news announcements.

As a result, for derivative pricing or risk assessment in the commodity market, it is necessary to study the market as a whole. Fundamental factors can capture a part of the volatility term structure. A better volatility forecast will improve production planning, inventory decisions and risk management.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from a number of repositories. The main data that support the findings of this study are available from Commodity Research Bureau (CRB). Restrictions apply to the availability of these data, which were used under license. Data are available at https://www.barchart.com/cmdty/data/datacenter with the permission of CRB. Further data that support the findings of this study were derived from the following resources available in the public domain: COMEX inventory report (https://www.cmegroup.com); Commitment of traders report (https://www.cftc.gov); Consumer sentiment index (https://data.sca.isr.umich.edu); EIA inventory report (https://www.eia.gov); Employment data (https://www.bls.gov); Equity variance risk premium (Hao Zhou); https://sites.google.com/site/haozhouspersonalhomepage); LME inventory report (https://www.lme.com); ICE inventory report (https://www.theice.com); Macroeconomic datasets (https://fred.stlouisfed.org/); Manufacturing index (https://www.instituteforsupplymanagement.org); Trade and production (https://www.census.gov); and USDA inventory report (https://www.nass.usda.gov/).

Further details about the data sources are in Table A1 of the Online Appendix.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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