

A bibliometric overview of volatility

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Abstract. Price volatility is a matter of importance for making decisions in the finance world. The growing studies regarding volatility have focused on minimizing the risks through modeling, estimating and forecasting. This paper presents a bibliometric overview of the most important authors, institutions and countries that work on the topic. Additionally, a historical analysis of how the agents have interrelated is presented. For the purposes of the analysis and the design of tables and graphics, tools from the Web of Science Core Collection and the VOSviewer software were used. The results show the importance of volatility in the study of business economics and decision making.

Keywords: Volatility, bibliometrics, Web of Science, VOSviewer

1. Introduction

In the last decades, a growing literature has emerged regarding modeling and forecasting dynamics in the volatility of financial markets. The global financial crises have generated a significant instability in the prices of financial assets [1, 2]. Measuring volatility forecasting and making decisions to hedge are important tasks for the policymakers, researchers and financial practitioners [3–5].

Volatility can be caused by many interconnected variables. Political-economic problems such as a financial crisis, major changes in the markets, generation of speculative bubbles, or switches in the monetary and debt management policies can cause instability [6, 7]. Additionally, domestic volatility can be caused by volatilities in different markets around the world [5, 8].

However, since volatility is not directly observable, it is usually estimated through parametric models

[9, 10]. Practitioners and researchers need to build a model with the capability to reproduce stylized facts based on observed time series that exhibit desirable statistical properties. In this sense, literature offers a set of models that adapt to one or more stylized facts. The existing parametric models for estimating the volatility include the popular ARCH–GARCH family [11, 12], the stochastic volatility models [13, 14] to a lesser extent, fuzzy models [15, 16], and artificial neural network models [17, 18].

Many reviews have been presented trying to compare different ways of volatility modeling. Poon and Granger [19] compare the volatility forecasting of existing models. Asai et al. [20] review specification, estimation, and evaluation of multivariate stochastic volatility models. Ait-Sahalia et al. [21] study the implied volatility in the model for forecasting. McAleer and Medeiros [22] review the volatility measure in high-frequency data. However, there is not a consensus on the best measures and volatility forecasting, due to the different instruments, horizons and scenarios.

This article proposes a bibliometric review of price volatility models in business economics and decision

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making. The main advantage of the paper is to offer a deep analysis of volatility studies and their interrelation. As part of this research, all the documents regarding volatility published between 1975 and 2018 were analyzed using the Web of Science Core Collection.

The results reveal a considerable increase of volatility studies in the last decades, resulting in more than twenty thousand papers in the area of business economics and decision making. The analysis reveals four facts: 1) The most important paper is the “Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation” proposed by Engle. 2) The most representative authors are McAleer M, Gupta R. and Bollerslev T. 3) The main institutions are the New York University, Columbia University and Duke University; and 4) The countries with the most publications regarding volatility are the USA, United Kingdom and China. Additionally, the most influential financial institutions on the topic are analyzed.

However, some fundamental investigations could be omitted if they are not found in the database or if another nomenclature has been considered to describe the phenomenon.

This work is organized as follows: 2) A description of the bibliometric methods used in the analysis; 3) An analysis of the publications structure, showing tables with the rankings of the best papers, authors, countries and institutions that study volatility; 4) A graphical analysis of the bibliographic data, and 5) A summary and conclusions.

2. Bibliometric methods

Bibliometric methods offer a convenient and non-reactive tool for studying collaboration in research. Pritchard [23] defines bibliometric analysis as the application of mathematical and communication methods to books and another media communication. A bibliometric study can produce many indicators such as productivity of authors, countries and universities. Additionally, this work includes information about co-authorship with journals, countries and universities. In the literature, many bibliometric studies have been analyzed in the areas of finance [24, 25], management [26, 27] and economics [28, 29].

To measure productivity, bibliometrics usually use the number of publications and their influence measured by the number of citations [30]. A very popular indicator to measure productivity is the h -index

which combines publications and citations in the same measurement [31]. Another alternative is to consider the ratio citation/papers or the impact factor by obtaining the mean of citation per paper. For the purpose of this work, we analyze both, the h -index and the impact factor.

The analysis considers other bibliometric indicators such as citation structure, which includes the number of papers that have surpassed a citation threshold, cites per paper, cites per year, citing articles, and their evolution through time. For the country analysis, a ratio of paper/million inhabitants is used. To analyze universities' productivity, the Academic Ranking of World Universities (ARWU) and the Quacquarelli and Symonds (QS) University Ranking are being considered.

To schematize the bibliometric analysis, we used the VOSviewer software [32]. The VOSviewer presents the information graphically, in terms of bibliographic coupling, citation, co-citation, co-authorship and co-occurrence of author keywords.

The study used the Web of Science Collection database that is currently owned by Clarivate Analytics with the indexes SCI-EXPANDED, SSCI, A&HCI and ESCI. The search topic keywords were “conditional heteroskedasticit* OR return volatility* OR conditional heteroscedasticit* OR stochastic volatility* OR volatility*”, which for purposes of this work will be considered as “volatility”. The search took place in May 2019. Note that the analysis only considered articles, reviews, letters and notes.

3. Results

3.1. Publication and citation structure

The number of publications regarding volatility from 1975 to 2018 were 22,004. Figure 1 shows the annual number of documents that have been

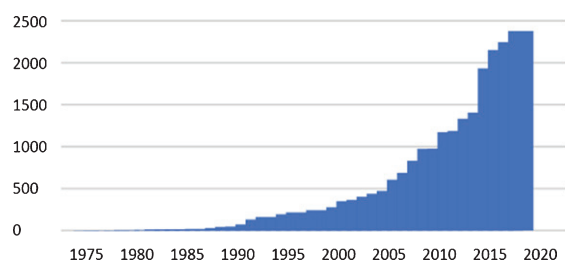


Fig. 1. Volatility papers published annually.

Table 1
The 40 most cited papers regarding volatility between 1975–2018

R	TC	Title	Author/s	Year	C/Y
1	7332	Autoregressive conditional heteroscedasticity with estimates of the variance of United-Kingdom inflation	Engle, RF	1982	192.9
2	6954	Generalized autoregressive conditional heteroskedasticity	Bollerslev, T	1986	204.5
3	3167	Conditional heteroskedasticity in asset returns – a new approach	Nelson, DB	1991	109.2
4	2737	A closed-form solution for options with stochastic volatility with applications to bond and currency options	Heston, SL	1993	101.3
5	2548	On the relation between the expected value and the volatility of the nominal excess return on stocks	Glosten, LR; Jagannathan, R; Runkle, DE	1993	94.3
6	1962	Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models	Engle, R	2002	109
7	1542	ARCH modeling in finance: – a review of the theory and empirical-evidence	Bollerslev, T; Chou, RY; Kroner, KF	1992	55.0
8	1475	Investor psychology and security market under- and overreactions	Daniel, K; Hirshleifer, D; Subrahmanyam, A	1998	67.0
9	1316	No contagion, only interdependence: Measuring stock market comovements	Forbes, KJ; Rigobon, R	2002	73.1
10	1316	Stock markets, banks, and economic growth	Levine, R; Zervos, S	1998	59.8
11	1260	Expected stock returns and volatility	French, KR; Schwert, GW; Stambaugh, RF	1987	38.1
12	1249	By force of habit: A consumption-based explanation of aggregate stock market behavior	Campbell, JY; Cochrane, JH	1999	59.4
13	1230	Measuring and testing the impact of news on volatility	Engle, RF; Ng, VK	1993	45.5
14	1213	The quality of accruals and earnings: The role of accrual estimation errors	Dechow, PM; Dichev, ID	2002	67.3
15	1190	Stock market Prices do not follow random walks: Evidence from a simple specification test	Lo, Andrew W; MacKinlay, A. Craig	1988	37.1
16	1174	The dividend price ratio and expectations of future dividends and discount factors	Campbell, John Y.; Shiller, Robert J.	1988	36.6
17	1072	Investor sentiment and the cross-section of stock returns	Baker, Malcolm; Wurgler, Jeffrey	2006	76.5
18	1069	The pricing of options on assets with stochastic volatilities	Hull, J; White, A	1987	32.3
19	1049	Modeling and forecasting realized volatility	Andersen, TG; Bollerslev, T; Diebold, FX; Labys, P	2003	61.7
20	1022	Market liquidity and funding liquidity	Brunnermeier, Markus K.; Pedersen, Lasse Heje	2009	92.9
21	996	Why does stock-market volatility change over time	Schwert, GW	1989	32.1
22	961	Answering the skeptics: Yes, standard volatility models do provide accurate forecasts	Andersen, TG; Bollerslev, T	1998	43.6
23	923	The cross-section of volatility and expected returns	Ang, A; Hodrick, RJ; Xing, YH; Zhang, XY	2006	65.9
24	907	Corporate disclosure policy and analyst behavior	Lang, MH; Lundholm, RJ	1996	37.7
25	893	Empirical performance of alternative option pricing models	Bakshi, G; Cao, C; Chen, ZW	1997	38.8
26	870	Market-based assets and shareholder value: A framework for analysis	Srivastava, RK; Shervani, TA; Fahey, L	1998	39.5
27	869	Extreme correlation of international equity markets	Longin, F; Solnik, B	2001	45.7
28	810	Risks for the long run: A potential resolution of asset pricing puzzles	Bansal, R; Yaron, A	2004	50.6
29	803	Fractionally integrated generalized autoregressive conditional heteroskedasticity	Baillie, RT; Bollerslev, T; Mikkelsen, HO	1996	33.4
30	798	The impact of uncertainty shocks	Bloom, Nicholas	2009	72.5
31	792	The territorial trap: the geographical assumptions of international relations theory	Agnew, John	1994	30.4
32	759	Giving content to investor sentiment: The role of media in the stock market	Tetlock, Paul C.	2007	58.3
33	756	Have individual stocks become more volatile? An empirical exploration of idiosyncratic risk	Campbell, JY; Lettau, M; Malkiel, BG; Xu, YX	2001	39.7
34	756	Corporate-debt value, bond covenants, and optimal capital structure	Leland, HE	1994	29.1
35	750	Jumps and stochastic volatility: Exchange rate processes implicit in deutsche mark options	Bates, DS	1996	31.2

(Continued)

Table 1
(Continued)

R	TC	Title	Author/s	Year	C/Y
36	748	The distribution of realized stock return volatility	Andersen, TG; Bollerslev, T; Diebold, FX; Ebens, H	2001	39.3
37	744	The stochastic behavior of commodity prices: Implications for valuation and hedging	Schwartz, ES	1997	32.3
38	744	Accounting earnings and cash flows as measures of firm performance – the role of accounting accruals	Dechow, PM	1994	28.6
39	726	Modelling asymmetric exchange rate dependence	Patton, AJ	2006	51.8
40	713	Stochastic volatility: Likelihood inference and comparison with ARCH models	Kim, S; Shephard, N; Chib, S	1998	32.4

Abbreviations: R = Rank; TC = Total citations; C/Y = Citations per year.

Table 2
The most cited publications regarding volatility

R	Year	Cited reference (only first author)	Type	citation	TLS
1	1986	bollerslev t, j econometrics, v31, p307	A	2586	2571
2	1982	engle rf, econometrica, v50, p987	A	2399	2386
3	1991	nelson db, econometrica, v59, p347	A	1674	1669
4	1993	glosten lr, j financ, v48, p1779	A	1471	1464
5	1973	black f, j polit econ, v81, p637	A	1432	1396
6	1993	heston sl, rev financ stud, v6, p327	A	1255	1235
7	1987	newey wk, econometrica, v55, p703	A	1103	1091
8	2002	engle r, j bus econ stat, v20, p339	A	913	906
9	1993	fama ef, j financ econ, v33, p3	A	876	871
10	1987	french kr, j financ econ, v19, p3	A	796	796
11	1993	engle rf, j financ, v48, p1749	A	722	722
12	2003	andersen tg, econometrica, v71, p579	A	700	700
13	1995	engle rf, economet theor, v11, p122	A	695	690
14	1992	bollerslev t, j econometrics, v52, p5	A	684	682
15	1992	bollerslev t., 1992, economet rev, v11, p143	A	668	666
16	1985	cox jc, econometrica, v53, p385	A	643	635
17	1989	schwert gw, j financ, v44, p1115	A	623	621
18	1989	hamilton jd, econometrica, v57, p357	A	615	606
19	1998	andersen tg, int econ rev, v39, p885,	A	611	611
20	1990	bollerslev t, rev econ stat, v72, p498	A	588	587
21	1985	kyle as, econometrica, v53, p1315	A	587	574
22	1994	hamilton j. d., time series anal	B	546	530
23	1997	bakshi g, j financ, v52, p2003	A	540	537
24	1973	merton rc, bell j econ, v4, p141	A	540	533
25	1993	ding z., j empir financ, v1, p83	A	537	537
26	1976	black f., p 1976 m am stat ass, p177	B	532	531
27	1987	engle rf, econometrica, v55, p251	A	531	517
28	1979	dickey da, j am stat assoc, v74, p427	A	523	518
29	1995	diebold fx, j bus econ stat, v13, p253	A	514	510
30	2006	ang a, j financ, v61, p259	A	508	508
31	2000	duffie d, econometrica, v68, p1343	A	508	507
32	1976	merton rc, j financ econ, v3, p125,	A	505	498
33	1973	fama ef, j polit econ, v81, p607	A	501	498
34	2001	andersen tg, j am stat assoc, v96, p42	A	497	497
35	1988	phillips pcb, biometrika, v75, p335	A	489	488
36	2001	andersen tg, j financ econ, v61, p43	A	480	480
37	2002	forbes kj, j financ, v57, p2223	A	478	474
38	1982	christie aa, j financ econ, v10, p407	A	476	476
39	1988	bollerslev t, j polit econ, v96, p116	A	467	467
40	1987	hull j, j financ, v42, p281	A	467	464

Abbreviations: A = Article B = Book; TLS = Total Link Strength.

published and it is observable that the number has considerably grown, especially in the last two decades.

In the first 17 years, publications were less than 100 per year. Then, an increase was observed in the decade of the nineties. The growth was accentuated in the first decade of the millennium. Since 2011 publications exceeded 1,000 per year. In 2016 they went up to 2,000. Nowadays, the growth is considerably significant.

Table 1 presents the forty most cited papers from 1975 to 2018. Note that the first places on the table correspond to works that study volatility modeling. The most cited paper was written by Robert Engle, winner of the Nobel Prize in economics in 2003 for his methods of analyzing economic time series with time-varying volatility, ARCH. The second most cited paper belongs to Tim Bollerslev who generalized the ARCH methods of Engle and proposed the GARCH model. In the third position, we find the work of Nelson that provides a new approach based on ARCH-GARCH models. On the other hand, the authors with the most cited papers are Bollerslev

with 5 papers, Campbell with 4, Engle with 3 and Andersen with 3.

In order to analyze the most cited documents and their relation with the topic of volatility we used the VOSviewer software and obtained the co-citations presented in Table 2. The most cited document was written by Bollerslev in [12], followed by the contribution of Engle. Note that Bollerslev and Engle lead this list with five publications in the table.

With the objective to analyze the citations structure, this work established thresholds and presented the information from 1991 to 2018 as seen on Table 3. It is observable that the majority of the most cited papers were published between 1990 and 2009. Only 1.5% of the publications have more than two hundred citations and 34% more than ten citations. While 80% of the papers about volatility have been cited at least once.

3.2. Leading authors, institutions and countries

In this section, authors, institutions and universities that have publications regarding volatility are

Table 3
Papers citation structure per year (1991–2018)

Year	TP	TC	≥200	≥100	≥50	≥20	≥10	≥5	≥1
1991	73	7089	6	14	23	36	42	54	67
1992	132	8894	10	21	36	63	86	100	122
1993	161	16243	17	33	60	89	108	125	149
1994	150	11236	15	26	46	76	94	103	139
1995	194	9007	11	24	43	83	109	140	178
1996	217	15231	23	40	68	104	137	159	201
1997	201	9568	10	27	49	82	115	148	192
1998	243	17043	18	37	63	106	149	179	224
1999	221	11344	13	29	58	108	149	174	203
2000	278	17533	21	48	83	150	187	221	259
2001	350	1934	24	52	101	175	246	285	335
2002	365	23481	22	55	99	192	245	305	349
2003	403	21503	27	56	104	192	259	330	288
2004	439	19125	17	47	102	213	294	372	423
2005	472	18411	15	44	92	209	300	374	456
2006	606	23269	14	48	119	264	381	467	576
2007	688	21049	9	52	121	266	393	511	646
2008	832	22146	12	43	121	300	471	621	783
2009	974	25734	17	39	130	324	522	692	922
2010	973	19111	4	30	93	277	465	682	903
2011	1171	21795	7	33	100	317	527	755	1074
2012	1187	18785	6	20	82	266	489	760	1091
2013	1332	16147	0	15	55	231	494	792	1212
2014	1407	14844	3	8	39	203	458	795	1261
2015	1932	11305	0	2	22	104	300	696	1588
2016	2151	9442	1	3	10	66	228	592	1618
2017	2245	5424	0	0	2	24	110	339	1416
2018	2376	1858	0	0	0	3	18	79	835

Abbreviations: TP and TC = Total papers and citations; ≥200, ≥100, ≥50, ≥20, ≥10, ≥5, ≥1 = number of papers with equal or more than 200, 100, 50, 20, 10, 5 and 1 citations.

Table 4
The most productive authors regarding volatility

R	Author name	University	Country	TP	TC	H	C/P	≥200	≥100	≥50
1	McAleer, Michael	Univ Western Australia	Australia	78	2135	23	27.37	1	4	12
2	Gupta, Rangan	Univ Pretoria	South Africa	78	503	12	6.44	0	0	0
3	Bollerslev, Tim	Duke Univ	USA	57	17305	39	303.59	13	23	35
4	Hammoudeh, Shawkat	Drexel Univ	USA	54	1041		19.27	0	2	5
5	Balcilar, Mehmet	Eastern Mediterranean Univ	Turkey	41	324	9	7.90	0	0	0
6	Bali, Turan G.	Georgetown Univ	USA	40	1591	22	39.77	1	3	9
7	Ghysels, Eric	Univ N Carolina	USA	38	2431	21	63.97	3	9	14
8	Bahmani-Oskooee, Mohsen	Univ Wisconsin	USA	37	195	7	5.27	0	0	0
9	Engle, Robert F.	NYU	USA	37	13350	29	360.81	10	16	25
10	Carr, Peter	NYU	USA	36	2178	22	60.5	3	8	12
11	Fabozzi, Frank J	EDHEC Business Sch	France	35	247	8	7.05	0	0	0
12	Duc Khuong Nguyen	IPAG Business Sch	France	35	1002	17	28.62	0	1	8
13	Andersen, Torben G.	Northwestern Univ	USA	34	6608	24	194.35	10	16	20
14	Narayan, Paresh Kumar	Deakin Univ, Deakin Business Sch	Australia	33	784	15	23.75	0	2	6
15	Tauchen, George	Duke Univ	USA	33	2568	21	77.81	4	6	13
16	Caporale, Guglielmo Maria	Brunel Univ London	England	31	327	10	10.54	0	0	1
17	Choudhry, Taufiq	Univ Southampton	England	31	266	9	8.58	0	0	0
18	Wohar, Mark	Univ Nebraska	USA	31	269	7	8.67	0	0	1
19	Bekaert, Geert	Columbia Univ	USA	30	4467	24	148.9	6	14	19
20	Ryu, Doojin	Sungkyunkwan Univ	South Korea	30	434	13	14.46	0	0	0
21	Serletis, Apostolos	Univ Calgary	Canada	30	532	12	17.73	0	1	2
22	Chevallier, Julien	IPAG Business Sch	France	29	351	9	12.10	0	1	1
23	Madan, Dilip B.	Univ Maryland	USA	29	829	10	28.58	1	2	5
24	Christoffersen, Peter	Univ Toronto	Canada	28	1224	16	43.71	0	3	11
25	Jacobs, Kris	Univ Houston	USA	28	1299		46.39	0	3	11
26	Kutan, Ali M.	Southern Illinois Univ	USA	28	255	9	9.10	0	0	1
27	McMillan, David G.	Univ Stirling	Scotland	28	100	5	3.57	0	0	0
28	Wong, Hoi Ying	Chinese Univ Hong Kong	China	28	233	10	8.32	0	0	0
29	Wu, Chongfeng	Shanghai Jiao Tong Univ	China	28	420	11	15	0	1	2
30	Brooks, Chris	Univ Reading	England	27	769	15	28.48	0	0	6
31	Herwartz, Helmut	Univ Kiel	Germany	27	189	7	7	0	0	1
32	Lee, Bong Soo	Henry W Bloch Sch Management	USA	27	473	11	17.51	0	1	3
33	Shephard, Neil	Harvard Univ	USA	27	3530	21	130.74	6	12	15
34	Tse, Yiuman	Univ Missouri	USA	27	482	13	17.85	0	0	3
35	Lien, Donald	Univ Texas San Antonio	USA	26	369	10	14.19	0	0	1
36	Aizenman, Joshua	Univ Southern Calif	USA	25	594	13	23.76	0	1	4
37	Caporin, Massimiliano	Univ Padua	Italy	25	189	6	7.56	0	0	1
38	Laurent, Sebastien	Aix Marseille Univ	France	25	1474	15	58.96	1	4	7
39	Pierdzioch, Christian	Helmut Schmidt Univ	Germany	25	146	6	5.84	0	0	0
40	Todorov, Viktor	Northwestern Univ	USA	25	651	14	26.04	0	1	3

Abbreviations available in Tables 1 and 3 except: C/P=Cites per paper; H = h-index.

analyzed. Table 4 shows the most productive authors. Michael McAleer from University of Western Australia is the most productive author with seventy-eight publications and he has been cited in two thousand one hundred thirty-five papers. In second place is Rangan Gupta with equal publications but fewer citations.

The list shows some authors with high h-index as Bollerslev, Engle, Andersen, Bekaert and Bali. It is important to note that almost half of the authors listed on the table are from the USA.

Table 5 analyzes the performance of the most productive authors through time; the information is presented in four periods of eleven years each. The productivity during the first period was low with an

average of three publications. Engle and Schiller were the most cited authors during this period. Between 1986–1996 the two most productive authors were Engle and Nelson. In the third period, Bollerslev ascended to the first position with twenty-three publications. In the last eleven years, Gupta has been the most productive author with seventy-seven papers on volatility.

In order to list the most productive and influential universities, we considered the last institution where the most productive authors have published their works.

In Table 6, USA universities appear with more frequency in the first three periods. However, from 2008 to 2018 European Universities became more relevant.

Table 5
The most productive authors and their performance by period

R	1975–1985			1986–1996		
	Author	TP	TC	Author	TP	TC
1	Kawai, M	3	42	Engle, RF	13	2894
2	Stock, D	3	6	Nelson, DB	12	3805
3	Anderson, RW	2	190	Bollerslev, T	11	10448
4	Hegde, SP	2	3	Baillie, RT	9	2533
5	Livingston, M	2	5	Brorsen, BW	9	182
6	Park, HY	2	16	Booth, GG	7	459
7	Schrems, EL	2	5	Harvey, CR	7	924
8	Schwartz, RA	2	15	Whaley, RE	7	746
9	Sears, RS	2	16	Chan, K	6	400
10	Shiller, RJ	2	413	Chan, KC	6	1094
11	Snyder, NH	2	44	Karolyi, GA	6	1395
12	Trennepohl, GL	2	13	Lastrapes, WD	6	495
13	Whitcomb, DK	2	15	Lee, JH	6	575
14	Engle, RF	1	7333	Seguin, PJ	6	603
15	Garman, MB	1	415	Tauchen, G	6	1174
16	Klass, MJ	1	415	Tucker, AL	6	92
17	Flavin, MA	1	107	Gallant, AR	5	1132
18	Pyburn, Philip J.	1	103	NG, VK	5	1429
19	Schmalensee, R	1	94	Kroner, KF	5	2124
20	Trippi, RR	1	94	Schwert, GW	5	3061

R	1997–2007			2008–2018		
	Author	TP	TC	Author	TP	TC
1	Bollerslev, T	23	5676	Gupta, Rangan	77	496
2	Bali, TG	18	550	McAleer, Michael	63	1130
3	Brooks, C	18	581	Hammoudeh, Shawkat	54	1042
4	Andersen, TG	17	5678	Balcilar, Mehmet	39	306
5	Ghysels, E	17	1710	Bahmani-Oskooee, Mohsen	36	173
6	McAleer, M	15	1005	Duc, Khuong Nguyen	35	1003
7	Subrahmanyam, A	14	3688	Fabozzi, Frank J.	33	244
8	Bekaert, G	13	3224	Narayan, Paresh Kumar	32	681
9	Diebold, FX	13	4517	Ryu, Doojin	30	434
10	Carr, P	12	1431	Chevallier, Julien	29	352
11	Devereux, MB	12	653	Wohar, Mark	29	219
12	Hong, YM	12	683	Wu, Chongfeng	27	417
13	Kanas, A	12	145	Wang, Yaw-Huei	26	376
14	Aizenman, J	11	333	Wong, Hoi Ying	26	190
15	Henry, OT	11	332	Caporale, Guglielmo Maria	24	244
16	Shephard, N	11	1933	Caporin, Massimiliano	24	183
17	Timmermann, A	11	778	Carr, Peter	24	747
18	Brandt, MW	10	979	Christoffersen, Peter	24	963
19	Laurent, S	10	1153	Jacobs, Kris	24	1038
20	Bakshi, G	10	1996	Todorov, Viktor	24	624

Abbreviations are available in the previous tables.

Since volatility is an important financial topic, this study also analyzes the most productive institutions that are not universities.

Table 7 shows the National Bureau of Economic Research leading the list with 574 publications. Note that the institutions publishing about volatility are the policy makers of influential countries.

Table 8 shows the 40 countries with most publications regarding the topic of volatility. The USA is the most productive country followed by the United Kingdom and China. If we consider the number of papers and cites per million inhabitants, the

most productive countries are Australia, Switzerland, Singapore, Denmark, New Zealand, Cyprus and Luxembourg with more than 50 publications per million inhabitants. Switzerland, Singapore and Denmark lead in the number of citations with more than 1000 cites per million inhabitants.

4. Graphical analysis of the information with VOSviewer

This section presents the graphical maps that resulted from the bibliometric networks analysis

Table 6
The most productive universities by period

R	1975–1985			1986–1996		
	University	TP	TC	University	TP	TC
1	University of California Berkeley	4	505	University of Chicago	33	8245
2	Johns Hopkins University	3	42	University of Pennsylvania	33	5485
3	Massachusetts Institute of Technology (MIT)	3	196	Duke University	27	4047
4	New York University	3	85	New York University	26	1700
5	University of Georgia	3	41	University of California San Diego	26	12927
6	University of Michigan	3	47	University of Michigan	23	4420
7	University of Oklahoma - Norman	3	6	Northwestern University	22	4249
8	University of Virginia	3	151	University of Wisconsin Madison	21	1169
9	Arizona State University	2	13	Columbia University	20	3936
10	Baruch College (CUNY)	2	19	Ohio State University	20	2201
11	George Washington University	2	3	Stanford University	20	809
12	Harvard University	2	25	University of California Berkeley	20	1840
13	Rutgers State University New Brunswick	2	15	Louisiana State University	19	830
14	Stanford University	2	53	Harvard University	18	1533
15	University of California San Diego	2	7427	University of Rochester	18	4597
16	University of Illinois Urbana-Champaign	2	16	Massachusetts Institute of Technology (MIT)	17	2680
17	University of Pennsylvania	2	413	Princeton University	17	4253
18	University of Wisconsin Parkside	2	5	University of North Carolina	17	2484
19	Washington University (WUSTL)	2	114	Vanderbilt University	16	1933
20	London School Economics & Political Science	1	7333	Arizona State University	14	967

R	1997–2007			2008–2018		
	University	TP	TC	University	TP	TC
1	University of London	114	5578	New York University	158	6445
2	Duke University	76	13873	Erasmus University Rotterdam	150	2049
3	Columbia University	65	8424	University of Amsterdam	150	2707
4	University of Pennsylvania	61	10472	Monash University	145	1397
5	University of California Los Angeles	58	7372	Columbia University	144	4134
6	University of California Berkeley	54	3606	Aarhus University	142	2490
7	Harvard University	52	8069	University of Oxford	141	3446
8	University of Chicago	52	8620	City University London	137	1794
9	Cornell University	50	3234	London School Economics & Political Science	130	2722
10	Massachusetts Institute of Technology (MIT)	49	7629	University of New South Wales Sydney	124	1240
11	University of Montreal	49	1950	University of Chicago	120	3637
12	Stanford University	48	7930	University of Sydney	118	888
13	Hong Kong University of Science & Technology	45	2683	Duke University	116	3820
14	University of Michigan	45	6262	University of Technology Sydney	116	882
15	University of North Carolina Chapel Hill	45	4142	IPAG Business School	114	1105
16	London School Economics & Political Science	44	3011	National University of Singapore	109	1345
17	University of California San Diego	43	6105	University of Montreal	106	940
18	University of Manchester	42	1700	University of Toronto	104	1559
19	Northwestern University	41	9208	University of Manchester	102	894
20	University of Maryland College Park	41	3442	Xiamen University	99	795

Abbreviation are available in Tables 1 and 3.

Table 7
The most productive institutions

R	Institution	Country	TP	TC	H	C/P	≥250	≥100	≥50
1	National Bureau of Economic Research	USA	574	54282	123	94.56	60	147	236
2	Federal Reserve System	USA	550	22814	73	41.48	15	40	100
3	International Monetary Fund	USA	231	5316	39	23.01	2	11	31
4	Centre National de la Recherche Scientifique (CNRS)	France	225	2746	29	12.20	0	2	11
5	Centre for Economic Policy Research	England	160	5798	39	36.23	4	15	32
6	European Central Bank	UE	124	4266	30	34.40	3	7	20
7	Federal Reserve System Board of Governors	USA	115	2633	27	22.89	0	6	15
8	The World Bank	USA	96	2123	21	22.11	0	6	13

Abbreviations are available in Tables 1 and 3.

Table 8
The most productive and influential countries regarding volatility

R	Country	TP	TC	H	C/P	≥250	≥100	≥50	P/Po	c/Po
1	USA	8194	315969	236	38.56	214	693	1372	25.076	966.96
2	United Kingdom	3132	65627	153	20.95	26	97	253	47.046	985.78
3	China	1849	19703	58	10.65	4	24	81	1.307	13.92
4	Germany	1442	20795	60	14.42	5	31	88	17.523	252.69
5	Australia	1423	17419	58	12.24	4	22	76	57.443	703.17
6	Canada	1249	23388	70	18.72	8	42	118	33.799	632.90
7	France	1242	18702	60	15.05	6	29	80	19.039	286.69
8	Taiwan	907	7481	39	8.24	0	5	28	38.280	315.73
9	Italy	898	10597	47	11.80	2	10	46	15.146	178.73
10	Spain	798	8984	43	11.25	2	8	37	17.199	193.63
11	Netherlands	673	14399	63	21.39	1	24	81	39.393	842.81
12	South Korea	640	7124	40	11.13	3	10	34	12.509	139.24
13	Switzerland	498	9107	48	18.28	2	19	46	58.286	1065.89
14	Turkey	458	4901	31	10.70	2	10	19	5.591	59.83
15	Japan	448	4289	29	9.57	1	7	18	3.522	33.72
16	Greece	387	3796	31	9.80	0	2	13	34.733	340.69
17	India	369	1478	17	4.00	0	1	3	0.273	1.09
18	Singapore	328	7075	39	21.57	4	17	34	56.631	1221.53
19	Denmark	327	15367	46	46.99	6	20	44	56.827	2670.50
20	Belgium	300	5661	37	18.87	1	9	25	26.090	492.32
21	New Zealand	270	2536	26	9.39	0	2	10	56.847	533.94
22	Sweden	252	4447	32	17.64	3	8	18	25.244	445.47
23	South Africa	227	928	16	4.08	0	0	0	3.955	16.17
24	Brazil	223	1946	21	8.72	0	4	7	1.058	9.23
25	Norway	212	2188	24	10.32	0	1	9	39.601	408.72
26	Czech Republic	193	1213	17	6.28	0	0	2	18.122	113.90
27	Austria	191	2361	24	12.36	1	3	11	21.824	269.77
28	Portugal	182	1985	20	10.90	0	4	7	17.685	192.88
29	Tunisia	177	1819	22	10.27	0	1	2	15.181	156.01
30	Finland	175	1836	25	10.49	0	0	5	31.574	331.26
31	Ireland	164	2341	24	14.27	1	2	10	34.140	487.33
32	Malaysia	164	996	16	6.07	0	1	3	5.118	31.08
33	Poland	151	600	13	3.97	0	0	0	3.963	15.75
34	Israel	132	1936	24	14.66	0	3	9	15.616	229.04
35	Pakistan	110	279	9	2.53	0	0	0	0.548	1.39
36	Chile	103	852	16	8.27	0	1	2	5.660	46.82
37	Romania	100	226	7	2.26	0	0	0	5.107	11.54
38	Russia	99	646	13	6.52	0	0	5	0.688	4.49
39	Saudi Arabia	94	623	14	6.62	0	0	2	2.801	18.57
40	U Arab Emirates	86	884	15	10.27	0	0	5	9.013	92.65

Abbreviations are available in previous tables, except $\frac{P}{PO}$, $\frac{C}{PO}$ papers and cites per million inhabitants.

using the software VOSviewer [32]. The maps include indexes such as co-citation, bibliographic coupling, citation analysis and co-authorship in order to analyze the influence and relationship among journals, publications of authors, institutions, countries and keywords.

In Fig. 2, the study analyzes the co-citation of journals regarding volatility. It presents the general analysis of the period 1975–2018 with a minimum threshold of five hundred cites and the one hundred most representative connections. Note that clusters are identified with different colors. One cluster regards the journals of mathematics, foreground publications in *Econometrica*, *Journal of Econometrics* and *Physic A*.

Another group of influential co-citations regards Economic Theory. The most cited journals in this field are the *American Economic Review*, the *Journal of International Money and Finance*, and the *Journal of Monetary Economics*. The leading journals in co-citation in the financial cluster are the *Journal on Finance* and *The Review of Financial Studies*. A fourth cluster includes the journals regarding management and business topics. While examining co-citation between clusters, it is observable that economic and econometric journals have a great tendency to cite financial journals.

Another interesting analysis is the bibliographic coupling among authors who publish about volatility. The resulting graph shown in Fig. 3 used data

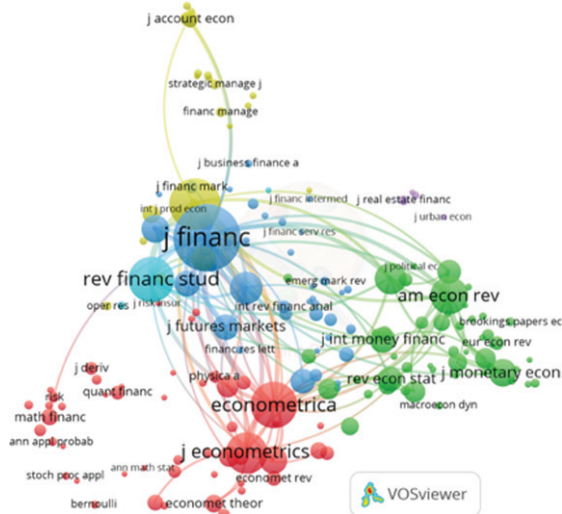


Fig. 2. Co-citation of journals regarding volatility.

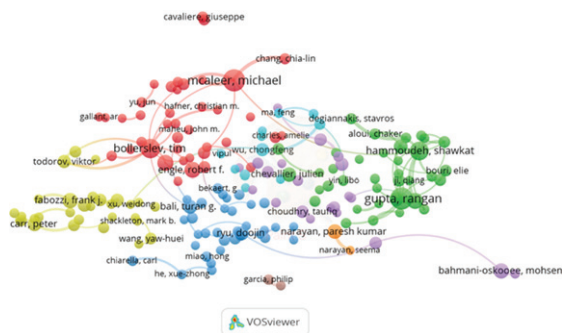


Fig. 3. Bibliographic coupling among authors publishing about volatility.

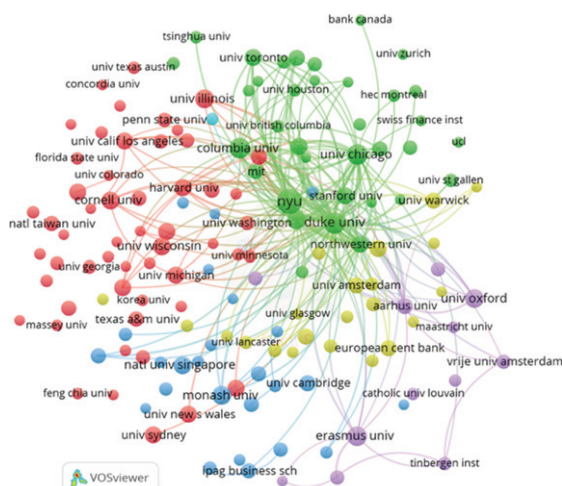


Fig. 4. Citation analysis by institutions.

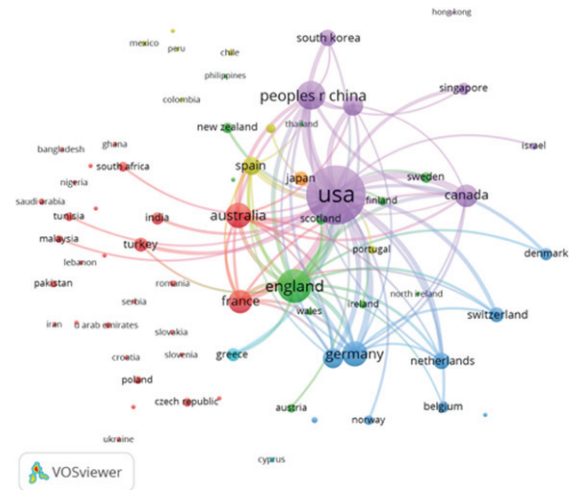


Fig. 5. Bibliographic coupling by countries.

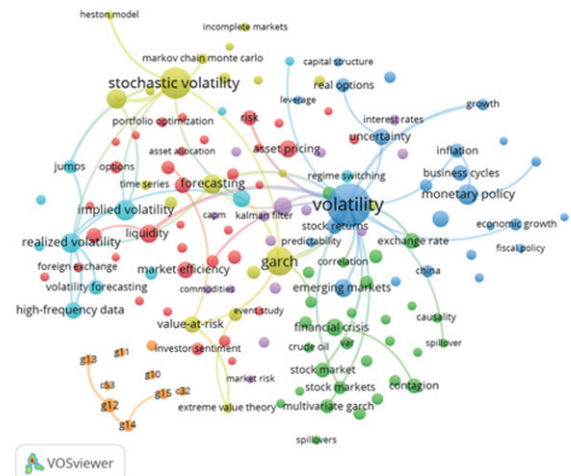


Fig. 6. Co-occurrence of author keywords in published documents regarding volatility.

with a minimum threshold of twelve papers and sixty cites. The featured authors in the graph are Michael McAleer, Tim Bollerslev and Rangan Gupta, also mentioned as the most productive authors in Table 4. Authors collaborate among themselves by countries or geographical areas. Note that in very few cases collaboration happens outside or beyond their research groups or areas.

Figure 4 shows an analysis of the citations by institutions, with a minimum threshold of fifty papers, five hundred cites and one hundred connections. The results are mostly grouped by geographical areas. The two largest groups are universities from the United States and they have great interaction among them

Table 9
Most common author keywords occurrences regarding volatility

R	Global			1986–1996			1997–2007			2008–2018		
	Keyword	OC	CO	Keyword	OC	CO	Keyword	OC	CO	Keyword	OC	CO
1	volatility	1303	903	volatility	26	16	volatility	237	162	volatility	1040	688
2	stochastic volatility	681	400	garch	20	14	stochastic volatility	135	92	stochastic volatility	529	262
3	garch	551	418	stochastic volatility	17	17	garch	112	82	garch	420	306
4	implied volatility	290	177	arch	14	13	exchange rates	68	54	realized volatility	258	191
5	monetary policy	287	151	exchange rates	10	7	option pricing	56	41	implied volatility	256	150
6	forecasting	286	203	option pricing	9	9	forecasting	49	45	monetary policy	236	112
7	option pricing	284	167	forecasting	8	8	monetary policy	49	33	forecasting	229	149
8	realized volatility	283	214	asset pricing	7	5	exchange rate volatility	38	19	option pricing	219	112
9	emerging markets	235	158	term structure	7	7	long memory	37	28	financial crisis	211	135
10	exchange rates	230	165	generalized method of moments	6	6	business cycles	34	12	emerging markets	202	136
11	liquidity	222	153	arch models	5	5	emerging markets	33	20	liquidity	202	133
12	financial crisis	215	148	business cycles	5	1	market microstructure	32	18	asset pricing	173	104
13	asset pricing	209	140	heteroskedasticity	5	5	implied volatility	30	21	long memory	165	123
14	long memory	203	153	options	5	4	risk	30	15	uncertainty	162	105
15	market efficiency	190	99	price volatility	5	3	asset pricing	29	23	value-at-risk	162	115
16	value-at-risk	190	144	cointegration	4	4	high-frequency data	29	23	market efficiency	161	75
17	uncertainty	189	130	conditional heteroskedasticity	4	3	trading volume	28	22	high-frequency data	156	115
18	exchange rate volatility	188	75	exchange rate volatility	4	4	value-at-risk	28	22	risk management	154	97
19	high-frequency data	185	141	finance	4	4	investment	27	17	exchange rate	153	101
20	exchange rate	179	123	futures markets	4	3	garch models	26	14	exchange rates	151	103
21	risk management	177	117	implied volatility	4	3	inflation	26	23	stock returns	150	99
22	stock returns	174	126	market microstructure	4	3	market efficiency	26	17	exchange rate volatility	146	59
23	business cycles	172	80	nonlinear filtering	4	4	price volatility	26	10	stock market	140	101
24	risk	163	99	stock returns	4	4	real options	26	10	volatility forecasting	140	98
25	market microstructure	156	100	unit root	4	4	term structure	26	17	contagion	138	98
26	volatility forecasting	156	110	chaos	3	2	uncertainty	26	20	g12	136	103
27	stock market	154	111	conditional volatility	3	1	arch	25	23	business cycles	133	54
28	contagion	150	109	garch models	3	3	exchange rate	25	20	risk	133	76
29	inflation	147	107	general equilibrium	3	3	kalman filter	25	19	inflation	121	85
30	real options	138	60	interest rates	3	3	markov chain monte carlo	25	23	market microstructure	120	78
31	g12	137	106	international	3	3	realized volatility	25	21	jumps	119	105
32	multivariate garch	134	95	market efficiency	3	1	hedging	24	15	multivariate garch	115	82
33	jumps	132	120	mean reversion	3	3	conditional heteroskedasticity	23	7	stock markets	115	88
34	garch models	126	76	quasi-maximum likelihood	3	3	learning	23	15	investor sentiment	114	68
35	hedging	126	87	smoothing	3	2	interest rates	22	15	structural breaks	114	85
36	stock markets	125	96	stock index futures	3	3	risk management	22	15	real options	112	46
37	value at risk	123	95	term structure of interest rates	3	1	garch model	21	11	china	110	55
38	price volatility	119	50	time-varying volatility	3	2	value at risk	21	16	volatility spillovers	109	70
39	asymmetry	118	89	vector autoregression	3	1	liquidity	20	13	vix	107	67
40	cointegration	118	63	volume	3	3	regime switching	20	14	economic growth	105	52

Abbreviations: OC = Author keyword occurrences; CO = Author keyword co-occurrences links.

as observed. European universities are part of the other three small groups, which have little interrelation with each other. Most of the universities in the United States are connected to the rest of the representative universities.

Figure 5 shows the bibliographic coupling of countries with a threshold of twenty documents and one hundred connections. It is observable that the United States has a close relationship with Scotland, Japan and Finland. Collaborative works regarding volatility can be found among the most representative countries: USA, China, England, Australia, Canada, Germany and France.

In order to analyze the words used by the authors, Fig. 6 shows the leading keywords in volatility papers. The Co-occurrence of author keywords analysis took into account a minimum threshold of fifty papers and one hundred connections. The most influential words are volatility, stochastic volatility, GARCH, realized volatility, forecasting and monetary policy. The words linkable to this study are estimation, forecast and modeling volatility. Words tend to be grouped into different clusters depending on other subtopics such as business and economics, financial markets, modeling and measures. The interrelationship between the representative words mainly occurs between the areas of modeling and volatility measurement.

Finally, in order to analyze the most common words through time, Table 9 shows the forty most used words along the general period and during three different periods: 1986–1996, 1997–2007 and 2008–2018. Volatility has been the most used keyword in all periods; GARCH was the second most used in the first period, while stochastic volatility is ranked in second place for the global period.

5. Summary and conclusions

Volatility is an important topic for financial management and decision making. Since volatility has an impact on prices, it becomes an influential indicator for investors, researchers and policymakers. Open markets and free trade have created continuous instability in the prices of financial assets. Exchange rates, indices and derivatives prices have been the most affected. In this sense, the literature has developed many proposals to counteract such problems.

Modeling, estimating and forecasting are the most important issues regarding volatility. This paper proposes a bibliometric analysis of volatility, modeling

and forecasting through time. The work comprises forty-four years between 1975–2018.

The paper also proposes an analysis of authors, institutions and countries who work in volatility, using comparative tables and graphical visualizations. Note that the information was retrieved from the database of the Web of Science Core Collection, and the maps were built with VOSviewer software. The analysis includes bibliographic coupling, co-authorship and co-citations, wherewith clusters and leading trends can be analyzed.

The most cited paper was written by Engle with 7,332 cites; his paper proposes an innovation in modeling and forecasting volatility. The USA is the most productive country through time with an annual number of publications well above the rest of the countries. Therefore, it is not strange that American universities lead the list of the most productive institutions regarding volatility. Other countries with high productivity are the United Kingdom and Germany while China has considerably increased its productivity in recent years.

This paper highlights the importance of studying volatility and how authors and institutions tend to work in groups by countries and geographical areas. It also shows how volatility has been studied from mathematical, financial and economic approaches over time.

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