

# Mapping of Barrier Option Pricing: A Co-citation Analysis

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**Abstract:** Barrier options refer to the options that are limited in the process of their entry into force. Its purpose is to control the investors' gains or losses within a certain range. Barrier options are a special form of options. Their emergence provides a more effective way for risk managers. In recent years, barrier options have developed rapidly in the financial market. Compared with ordinary options, their trading methods are more flexible, their returns are in line with investors' wishes, and their trading prices are cheaper. They are popular with investors. Therefore, how to price barrier options has become an important research hotspot in the financial field. There is a very obvious phenomenon that the publications about barrier option pricing increasing year by year. Based on the literature data retrieved from Web of Science, this paper adopts the scientometrics analysis method to make a literature review on the pricing of barrier options, an analysis of current research situation, a co-citation analysis of literature, new trends and developments in the research field, and an analysis of sudden detection in the research field. It is concluded that "Business Finance" is the most popular subject in the field of barrier option pricing, and "Quantitative Finance" is the most frequently published journal. Among many countries in the world, USA has the largest number of publications in this field. In the field of barrier option pricing, "China University of Hong Kong" has the largest number of publications, and "general valuation framework", "flexible binomial option pricing model", "model uncertainty", "evy processes", "early exercise boundary", "model" are the main research fields of barrier option pricing. Math Finance and Merton RC are the most influential journals and authors in the field of barrier option pricing. On the whole, the research method in this paper provided a fresh research approach to assess the performance of barrier option pricing research. The findings may help for the new researchers to pick out the most relevant articles, journals, institutions and seize the research frontier in barrier option pricing field.

**Keywords:** Barrier Options, Option Pricing, Co-citation Analysis, Web of Science

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## 1. Introduction

At present, the study of option pricing has become an important means to reduce risk. As a special kind of option, barrier options have some differences in pricing methods from ordinary options. Under this background, visual analysis of different scholars' research on barrier options pricing plays an important role in grasping the development trend of future options. Jun et al. [1] studied the pricing of exponential barrier options. By comparing different types of barrier options, the pricing formulas of exponential barrier options were obtained when they were linked together. Barone-Adesi et al. [2] according to different types of barrier options, the probability adjustment model is used to find out how to use the least effort to calculate the exact approximation of the option price.

Horfelt [3] The pricing of discrete barrier options is studied, and the formulas of put options and double barrier options are verified in practice. Broadie et al. [4] use the continuous barrier formula to study the pricing formula of discrete barrier options by simply correcting the continuity of the barrier. Roberts et al. [5] give a general technique for calculating or accurately estimating the price of barrier options. Using the method of estimating the boundary hit time of diffusion process, a simple and easy-to-use method for calculating the price of barrier options is obtained.

Although the importance of barrier option pricing and the number of research papers published are increasing, there is little analysis on the current situation and development trend of barrier option pricing. Scientometric is the quantitative analysis of input, output and process for scientific activities

based on mathematical statistics and computing technology and other mathematical methods, it is the discipline aims to find out the rules of scientific activities.

With the continuous growth of importance and popularity, barrier option pricing has entered a critical stage of development. As the focus of this study, it is very important and urgent to summarize the research status and analyze the future development trend.

## 2. Data Collection and Research Method

The purpose of this paper is to visualize the research of barrier option pricing and retrieve literature data from Web of Science by using literature retrieval strategy.

Topics= "Barrier option pricing"

Timespan= "All year"

Databases=Science Citation Index Expanded (SCI-EXPANDED) /Social Sciences Citation Index (SSCI)/Arts & Humanities Citation Index (A&HCI)/Conference Proceedings Citation Index-Science (CPCI-S)/Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH) and Emerging Sources Citation Index (ESCI)

Lemmatization=On

The data is considered valid if the pricing of an obstacle option appears in three fields, including summary, keyword and the title of the download record. Under these conditions, 880 documents were retrieved and downloaded on January 10, 2019. The number of publications per year is shown in Figure 1.

Based on the collected literature, it is found that the first article on barrier option pricing was published in 1991. In the past decades, the number of publications on barrier option pricing increased from 2 in 1994 to 79 in 2018. On the other hand, the number of publications is increasing every year, which fully illustrates that the research of barrier option pricing has attracted more and more attention. The number of references cited annually is detailed in Figure 2.

There are ten types of literature on the pricing of barrier options. Such as Business Finance, Economics, Mathematics Interdisciplinary Applications, Mathematics Applied, Social Sciences Mathematical Methods, Statistics Probability, Operations Research, Management Science, Energy Fuels, Environment Sciences. The detailed documents types are illustrated in Figure 3.

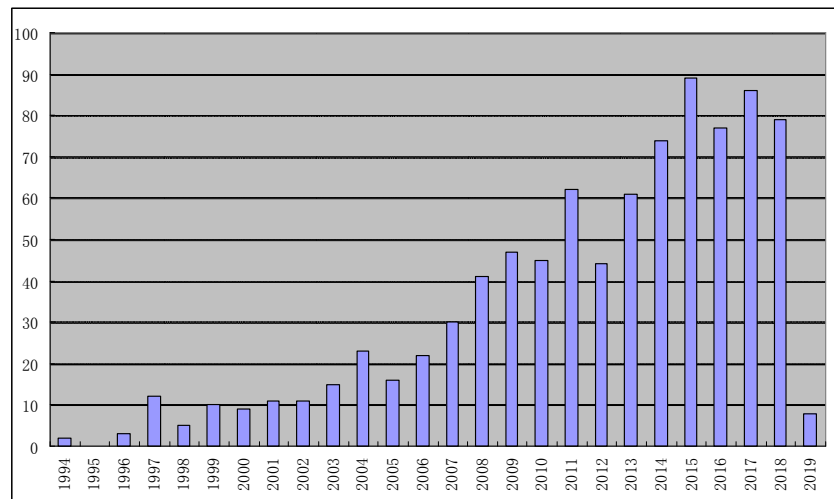


Figure 1. Number of publications in Barrier option pricing area.

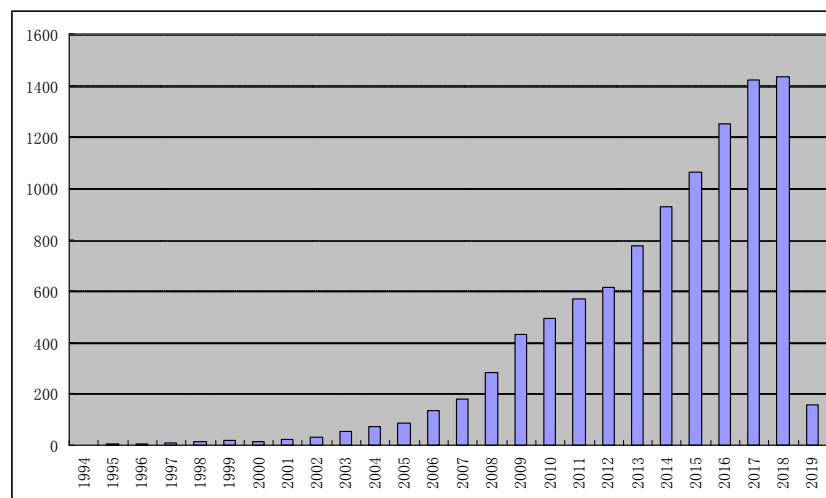


Figure 2. Number of citations per year in Barrier option pricing area.

Table 1 shows the types of 880 documents for barrier option pricing. According to the search strategy described in the previous section, more than 880 articles were downloaded, because sometimes an article can be divided into two different document types at the same time. Through Science Net, it is found that the research on barrier option pricing spans many disciplines.

Table 1 clearly tells us that "Business Finance" is the most popular subject category, with 270 publications, accounting for 30.303% of the total publications. Economics is the second

most popular subject category after Business Finance, with 204 publications, accounting for 22.896% of the total publications. The third place was Mathematics Interdisciplinary Applications, which published 161 copies, accounting for 18.070%. The fourth to tenth categories are Mathematics Applied, Social Sciences Mathematical Methods, Statistics Probability, Energy Fuels, Operations Research Management Science, Environmental Sciences, and Management.

**Table 1.** The top 10 subject categories in Barrier option pricing area.

Subject categories	Publication Number	The percentage of total
Business Finance	270	30.303%
Economics	204	22.896%
Mathematics Interdisciplinary Applications	161	18.070%
Mathematics Applied	138	15.600%
Social Sciences Mathematical Methods	130	14.590%
Statistics Probability	90	10.101%
Energy Fuels	67	7.520%
Operations Research Management Science	53	5.948%
Environmental Sciences	46	5.163%
Management	45	5.051%

**Table 2.** The top 10 journals in Barrier option pricing area.

Subject categories	Publication Number	The percentage of total
Quantitative Finance	45	5.051%
Journal of Computational and Applied Mathematics	28	3.143%
Mathematical Finance	26	2.918%
Finance and Stochastics	20	2.245%
Journal of Futures Markets	18	2.020%
Siam Journal on Financial Mathematics	17	1.908%
Journal of Derivatives	16	1.796%
Journal of Computational Finance	15	1.684%
Energy Policy	14	1.571%
Journal of Banking Finance	14	1.571%

Hundreds of scholars have published their research results on barrier option pricing. Table 2 shows the top 10 mid-term publications in the field of barrier option pricing. From Table 2, it is found that the number one journal is Quantitative Finance, which has published 45 papers on the pricing of barrier options, accounting for 5.051% of the total number of papers. Journal of Computation and Applied Mathematics ranked second, with 28 papers, accounting for 3.143%. Next come Mathematical Finance, which published 26 papers, accounting for 2.918%. The fourth to tenth ranked journals are "Finance and Stochastic", "Journal of Futures Markets", "Siam Journal on Financial Mathematics", "Journal of Derivatives", "Journal of Computational Finance", "Energy Policy" and "Journal of Banking Finance".

The study of barrier option pricing has received different attention from different countries and regions. Table 3 shows 10 countries with the most growth in the field of barrier option pricing. From Table 3, it is found that USA has the largest number of publications in this field, with 182 articles,

accounting for 20.426%, followed by Peoples R China, with 128 articles, accounting for 14.366%. The third place was England, which published 67 articles, accounting for 11.336%. The fourth to tenth countries are Australia, Germany, Italy, Canada, France, Taiwan and Netherlands.

**Table 3.** The top 10 most productive countries in Barrier option pricing area.

Country/Territories	Number	The percentage of total
USA	182	20.426%
Peoples R China	128	14.366%
England	101	11.336%
Australia	67	7.520%
Germany	65	7.295%
Italy	58	6.510%
Canada	53	5.948%
France	46	5.163%
Taiwan	38	4.265%
Netherlands	32	3.591%

*Table 4. The top 10 most productive institutions in Barrier option area.*

Institutions	Number	The percentage of total
Chinese University of Hong Kong (China)	22	2.469%
University of London (England)	19	2.132%
National Taiwan University (China)	17	1.908%
University of Waterloo (Canada)	17	1.908%
Imperial College London (England)	16	1.796%
Technical University Kosice (Slovakia)	15	1.684%
Columbia University (USA)	12	1.347%
University of California System (USA)	12	1.347%
University of North Carolina (USA)	12	1.347%
Delft University of Technology (Netherlands)	11	1.235%

As can be seen from Table 4, Chinese University of Hong Kong has published the largest number of papers in the field of barrier option pricing, with a total of 22 papers, accounting for 2.469%. University of London ranked second, with 19 articles published, accounting for 2.132%. Next come National Taiwan University, which published 17 articles, accounting for 1.908 per cent. Fourth to tenth were "University of Waterloo", "Imperial College London", "Technical University Kosice", "Columbia University", "University of California System", "University of North Carolina" and "Delft University of Technology". Of the 10 research institutes mentioned above, there are three schools in the United States, two in China and two in Britain, and the remaining three are from Canada, Slovakia and Netherlands.

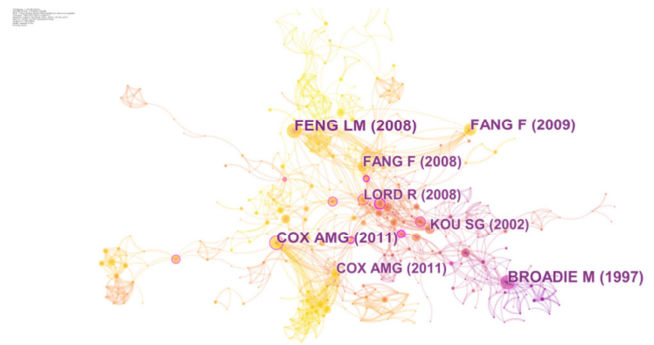
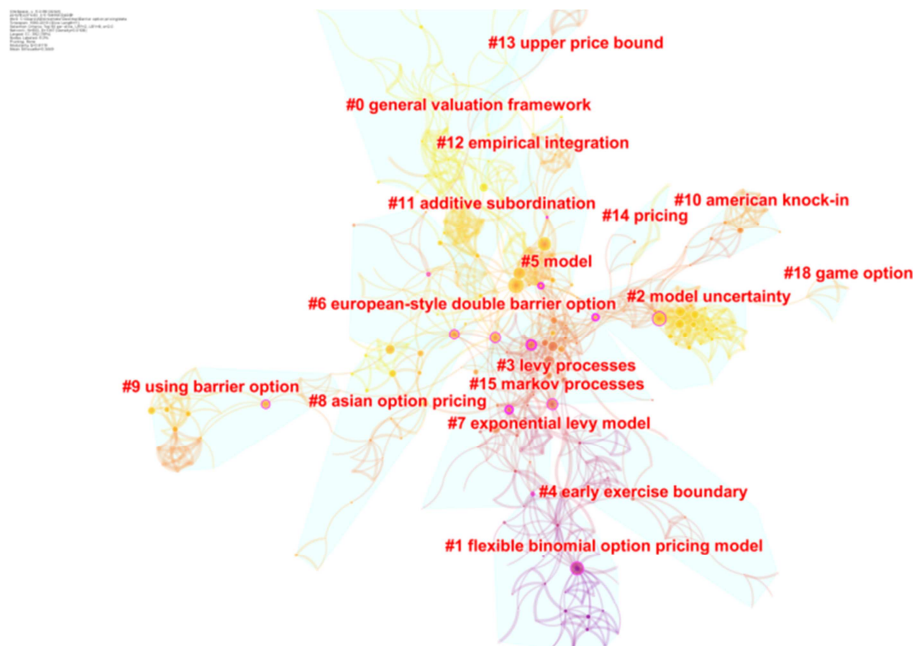
### 3. Co-citation Analysis in Barrier Option Pricing Research Area

Document co-citation analysis is to determine the key documents or core documents which have had great influence on the regarding research area through the analysis of citation frequency of the documents by other literature simultaneously. By using the document cogitation analysis method, it is found

that the key literature and major research area in barrier option pricing domain.

#### 3.1. Research Clustering in Barrier Option Pricing

Figure 3 is the full picture of the literature co-citation network. Figure 4 is the main cluster of barrier option pricing research. The network is divided into 17 co-citation clusters. These clusters are labeled by index terms from their own citers. The largest 6 clusters are summarized in Table 5.

*Figure 3. Full shot of document co-citation network.**Figure 4. Cluster network in Barrier option pricing area.*

**Table 5.** The top 10 most productive institutions.

Cluster ID	Size	Silhouette	Label (TFIDF)	Label (LLR)	Mean (Cited Year)
0	43	0.933	pricing	general valuation framework	2013
1	41	0.953	pricing	flexible binomial option pricing model	1996
2	39	0.832	robust hedging	model uncertainty	2011
3	32	0.75	option pricing	levy processes	2004
4	31	0.929	pricing	early exercise boundary	2001
5	31	0.848	pricing	model	2009

In Table 5, Size indicates the numbers of the publications in the cluster. For example, the largest cluster (#0) has 43 members and the second largest cluster (#1) has 41 members. The third cluster (#2) has 39, the fourth cluster (#3) has 32, the fifth cluster (#4) has 31 and the sixth cluster (#5) has 31. From Table 5, it is found that Silhouette is an index to measure the homogeneity of a cluster, the greater value of this index, the better of the homogeneity. From Table 5, it is found that the second largest cluster is the best homogeneity (#1), and the fourth largest cluster is the worst homogeneity (#3). TFIDF (term frequency-inverse document frequency) is a commonly used weighting technique for information retrieval and data mining. In this Section, the TFIDF method was used to label the cutters. LLR is an index marking various clusters as different options pricing models. The last column in Table 5 is the index of Mean (Cited Year). This represents the average year of the published documents of the regarding cluster. It is a very useful index since it can be used to judge the cluster whether it is new or old. For example, from Table 5, it is found that the Cluster 0 and Cluster 2 were newly formed Clusters, this means that "Pricing" and "robust hedging" are the hot issues recently in barrier option pricing research area.

The largest cluster (#0) has 43 members and a silhouette value of 0.933. It is labeled as general valuation framework by LLR, pricing by TFIDF. The most active citer to the cluster is 0.321 Cui, Zhenyu (2018) A general valuation framework for sabra and stochastic local volatility models. The second largest cluster (#1) has 41 members and a silhouette value of 0.953. It is labeled as flexible binomial option pricing model by LLR, pricing by TFIDF. The most active citer to the cluster is 0.2331 Tian, YS (1999) A flexible binomial option pricing model. The third largest cluster (#2) has 39 members and a silhouette value of 0.832. It is labeled as model uncertainty by LLR, robust hedging by TFIDF. The most active citer to the cluster is 0.2811 Herrmann, Sebastian (2017) Model uncertainty, recalibration, and the emergence of delta-Vega hedging. The 4th largest cluster (#3) has 32 members and a silhouette value of 0.75. It is labeled as levy processes by LLR, option pricing by TFIDF. The most active citer to the cluster is 0.29191 Levendorskii, SZ (2004) Early exercise boundary and option prices in levy driven models. The 5th largest cluster (#4) has 31 members and a silhouette value of 0.929. It is labeled as early exercise boundary by LLR, pricing by TFIDF. The most active citer to the cluster is 0.29191 Levendorskii, SZ (2004) Early exercise boundary and option prices in levy driven models. The 6th largest cluster (#5) has 31 members and a silhouette value of 0.848. It is labeled as model by LLR, pricing by TFIDF. The most active citer to the cluster is

0.3231 Hieber, Peter (2014) First-passage times of regime switching models.

### 3.2. The Most Cited Literature in the Field of Barrier Option Pricing

Table 6 lists the 10 most cited papers in the field of barrier option pricing. Glanz, Karen, Sallis, James F., Saelens, Brian E., Frank, Lawrence D. published Nutrition environment survey in stores (NEMS-S) - Development and evaluation in American Journal of Preventive Medicine is the most cited paper in our database [8]. Smith, Pete; Martino, Daniel; Cai, Zucong; Gwary, Daniel; Janzen, Henry; Kumar, Pushpam; McCarl, Bruce; Ogle, Stephen; O'Mara, Frank; Rice, Charles; Scholes, Bob; Sirotenko, Oleg; Howden, Mark; McAllister, Tim; Pan, Genxing; Romanenkov, Vladimir; Schneider, Uwe; Towprayoon, Sirintornthep, Ecotourism system on Environment and Environment and Published Policy and Technical constraints to implementation of greenhouse gas mitigation options in agriculture were cited second [9], followed by Kou, SG; Wang, H. Option pricing under a double exponential diffusion model [10] published on Management Science. Of the above 10 articles, two are from American Journal of Preventive Medicine [8, 17], two are from Management Science [10, 14], and the remaining are from Agriculture Ecosystems & Environment [9], International Journal of Hydrogen Energy [11], Renewable Energy [12], Advances in Applied Probability [13], and Siam Journal on Digital Analysis, respectively.[15], Bmj Open [16].

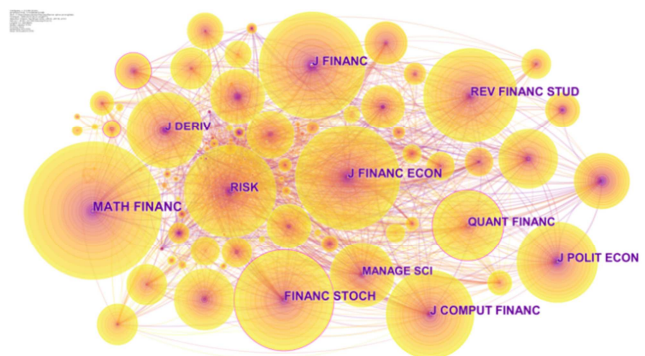
**Figure 5.** Main journals cluster in Barrier option pricing area.

Figure 5 shows the clustering of major journals in the field of barrier option pricing. Table 7 shows the top 10 journals in the field of barrier option pricing. Top journals in the field are Math Finance, J Finance, J Finance Econ, Finance Stoch, Rev Finance Stud, Risk, J Comput Finance, J Polit Econ.



**Table 6.** The top 10 journals according to frequency.

Frequency	Centrality	Journals	Half-life
327	0.04	Math Financ	16
267	0.02	J Financ	16
265	0.01	J Financ Econ	14
250	0.14	Financ Stoch	14
241	0.03	Rev Financ Stud	14
234	0.02	Risk	16
228	0.09	J Comput Financ	14
206	0.08	J Polit Econ	20
197	0.02	J Deriv	16
178	0.16	Quant Financ	10

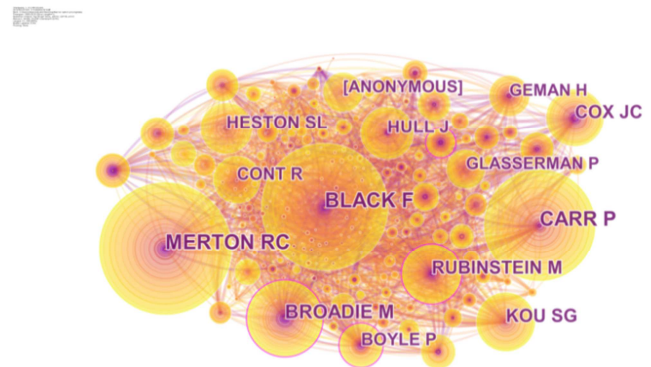
**Table 7.** The top 10 references in Barrier option pricing area.

Citation Number	Number of citation per year	Title	Authors	Source	Year
332	25.54	Nutrition environment measures survey in stores (NEMS-S) - Development and evaluation	Glanz, Karen; Sallis, James F.; Saelens, Brian E.; Frank, Lawrence D.	American Journal of Preventive Medicine	2007
260	20	Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture	Smith, Pete; Martino, Daniel; Cai, Zucong; Gwary, Daniel;	Agriculture Ecosystems & Environment	2007
209	13.06	Option pricing under a double exponential jump diffusion model	Kou, SG; Wang, H	Management Science	2004
198	15.23	Techno-economic assessment of hydrogen production processes for the hydrogen economy for the short and medium term	Mueller-Langer, F.; Tzimas, E.; Kaltschmitt, M.; Peteves, S.	International Journal of Hydrogen Energy	2007
176	14.67	Comparison of feed-in tariff, quota and auction mechanisms to support wind power development	Butler, Lucy; Neuhoﬀ, Karsten	Renewable Energy	2008
175	10.29	First passage times of a jump diffusion process	Kou, SG; Wang, H	Advances in applied probability	2003
159	8.37	Pricing and hedging path-dependent options under the CEV process	Davydov, D; Linetsky, V	Management Science	2001
158	10.53	A finite difference scheme for option pricing in jump diffusion and exponential Levy models	Cont, R; Voltchkova, E	Siam Journal on Numerical Analysis	2005
150	21.43	Do healthier foods and diet patterns cost more than less healthy options? A systematic review and meta-analysis	Rao, Mayuree; Afshin, Ashkan; Singh, Gitanjali; Mozaffarian, Dariush	Bmj Open	2013
150	11.54	Nutrition environment measures study in restaurants (NEMS-R) - Development and evaluation	Saelens, Brian E.; Glanz, Karen; Sallis, James F.; Frank, Lawrence D.	American Journal of Preventive Medicine	2007

**Table 8.** The top 10 authors according to frequency in Barrier option pricing.

Frequency	Centrality	Author	Half-life
231	0.06	Merton RC	16
221	0.07	Black F	16
198	0.09	Carr P	14
139	0.14	Broadie M	14
115	0.11	Rubinstein M	16
107	0.03	Cox JC	14
105	0.05	Kou SG	11
97	0.04	Hull J	14
94	0.07	Heston SL	10
88	0.11	Boyle P	15

Figure 6 shows the cluster of leading authors in the field of barrier option pricing. Table 8 shows the top 10 authors in the field. The most representative authors are Merton RC, Black F, Carr P, Broadie M, Rubinstein M, Cox JC, Kou SG, Hull J, Heston SL, Boyle P.

**Figure 6.** Main authors cluster in Barrier option pricing area.

#### 4. Burst Detection in Barrier Option Pricing Research Area

The entity with frequency burst means it has abrupt change of the frequency in a certain period of time [6, 7]. Burst

detection is an invaluable analytic mean and it is available on the types of references, keywords, authors, and institutions.

#### 4.1. Trends and Developments in Barrier Options Pricing

An article with citation burst means it received specific attentions from the academic circles in a certain period of time. Further, if a research cluster contains a certain amount articles with citation burst, then the research cluster can be recognized as the new emerging trend. Through the analysis of dataset, it is found that they are there. A lot of articles with citation bursts and the top 10 articles are listed in Figure 7.



Figure 7. References with the Strongest Citation Bursts.

Through the burst monitoring of keywords, it is found that the fast developing topic in the field of barrier option pricing. The first four key words burst are as follows: Figure 8.

The research results show that the research topic changes with time. In the 1990s, barrier option was a hot topic in the field of barrier option pricing research, which broke out in 1999 and lasted until 2003. It can be seen that barrier option, as a new hot topic, attracted a large number of scholars in the

initial stage of the study. Research. With the deepening of the research, it can be seen from the table that levy process has become a hot topic in recent years. The outbreak lasted from 2010 to 2012. Under the background of the emergence of a large number of barrier option pricing studies, scholars tend to combine the barrier option pricing with the tax process. Through research and analysis, an effective pricing model suitable for all kinds of barrier options will be found.



Figure 8. Keywords with the Strongest Citation Bursts.

#### 4.2. Institutional Burst Detection in Barrier Option Pricing Research

Through the sudden detection of research institutions, it is identified that the institutions with more active identities at some time in relevant research fields. From Figure 9, it is found that the institutions of the Chinese University of Hong

Kong broke out in 2006 and ended in 2009. This shows that researchers from the Chinese University of Hong Kong spent a lot of time and energy on the research of barrier option pricing in 2006-2009. Seoul University, which broke out in 2016 and ended in 2019, has received great attention in the three-year period from 2016 to 2019.



Figure 9. Institutions with the Strongest Citation Bursts.

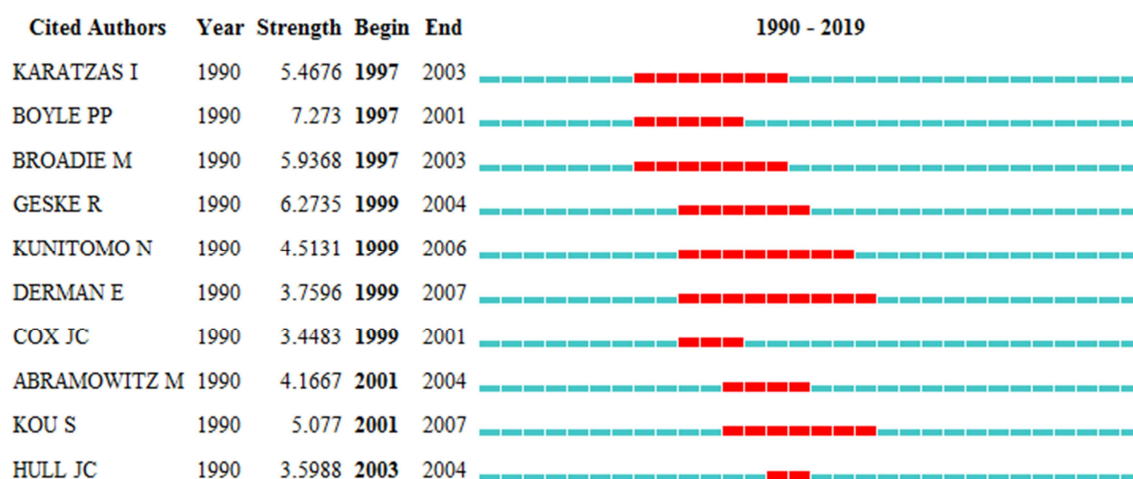


Figure 10. Cited Authors with the Strongest Citation Bursts.

#### 4.3. Author Sudden Detection in the Pricing of Barrier Options

By further studying the author burst detection in the field of barrier option pricing, it is identified that the authors who rapidly increase the number of publications. The first 10 authors' burst detection is listed in Figure 10. The suddenness of Karatzas I, which began in 1997, lasted from 1997 to 2003. This shows that the number of publications of the author in the field of barrier option pricing has been increasing in the past seven years. In the nine years from 1999 to 2007, Derman E's articles in the field of barrier option pricing have been on the increase. Cox JC, Abramowitz M and Hull JC had a relatively short growth period. The outbreak years of Abramowitz M and Hull JC were 1999-2001, 2001-2004 and 2003-2004, which lasted three, four and two years respectively.

## 5. Conclusions

In this paper, 880 documents retrieved from the scientific network were evaluated scientifically, and some useful conclusions for researchers were obtained. Firstly, "Business Finance" is the most popular subject category in the field of barrier option pricing, "Economics" is the second most popular subject category after "Business Finance". The third is "Mathematics Interdisciplinary Applications", the fourth is "Mathematics Applied", and the fifth is "Social Sciences Mathematical Methods". Quantitative Finance has published the highest number of articles in the field of barrier option pricing, followed by Journal Of Computation and Applied Mathematics, followed by Mathematical Finance, which has published 26 articles, accounting for 2.918%. Fourth is Finance and Stochastic, and fifth is Journal Of Futures Markets. USA has the largest number of publications in this field in many countries around the world, followed by Peoples R China, Britain ranked third, Australia ranked fourth and Germany ranked fifth. China University of Hong Kong has the largest number of papers published in the field of barrier option pricing, ranking second in the number of papers, followed by National Taiwan University, ranked fourth in the

number of "University of Waterloo" and fifth in the number of "Imperial College London". Secondly, "general valuation framework", "flexible binomial option pricing model", "model uncertainty", "levy processes", "early exercise boundary", "model" are the main research fields of barrier option pricing. In addition, Glanz, Karen, Sallis, James F., Saelens, Brian E., Frank, Lawrence D. published Nutrition environment measures survey in stores (NEMS-S) - Development and evaluation in American Journal of Preventive Medicine, which is the most cited paper in the database. Smith Pete Martino, Pete Martino, Daniel; Cai, Zucong; Gwary, Daniel; Janzen, Henry; Kumar, Pushpam; McCarl, Bruce; Ogle, Stephen; O'Mara, Frank, Frank Rice, Charles, Scholes, Bob; Sirotenko, Oleg; Howden, Mark McAllister, McAllister, Tim Timpan, Genxing; Romanenko, Romanenkov, Vladimir; Vladimir; Schneider, Uider, Uider, Uider, Siprayer, Agrepepererererhope, Agrecotore, Ecotortortore system on Environment and Environvirement and EnvirPublished Policy and Technical constraints to implementation of greenhouse gas mitigation options in agriculture ranked second, followed by Kou, SG; Wang, H. Option pricing under a double exponential jump diffusion model published on Management Science. Math Financ, J Financ, J Financ Econ, Financ Stoch, Rev Financ Stud, Risk, J Comput Financ, J Polit Econ, J Deriv, Quant Financ are the most influential journals in the field of barrier option pricing. The representative authors are Merton RC, Black F, Carr P, Broadie M, Rubinstein M, Cox JC, Kou SG, Hull J, Heston SL, Boyle P. Thirdly, "general valuation framework" and "model uncertainty" are emerging research trends in the field of barrier option pricing, and levy process has become a hot topic in recent years.

Through the research and analysis of this article, it is found that in the future research on the pricing of barrier options, researchers should focus on "Business Finance", "Economics", "Mathematics Interdisciplinary Applications", "Mathematics Applied" and "Social Sciences Mathematical Methods". Focus on "Quantitative Finance", "Journal of Computation and Applied Mathematics", "Mathematical Finance", "Finance and Stochastic", "Journal of Futures Markets" five



more influential journal articles to summarize and analyze. The research results of sudden detection show that in recent years, the research on barrier option pricing should be combined with various hot topics, such as taxation and other topics of concern to enterprises and citizens. By combining with hot topics, the opinions and suggestions of the research results can better fit the current situation of economic development. On the other hand, this study provides an overview of the development of barrier option pricing research. In the future, researchers should learn to summarize and analyze the advantages and disadvantages of the current research. On the basis of fully learning from previous studies, they should constantly explore the hot trends of future research and further improve the deficiencies of barrier option pricing research.

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