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International scientific collaboration in the research system: dynamics, opportunities and challenges for Kazakhstan

Abstract. *Introduction.* International scientific collaboration and science diplomacy are essential components of international relations and international law, facilitating cross-cultural interactions at various political, societal, social, humanitarian, and technical levels. The sphere of international scientific collaboration, increasingly intertwined with science diplomacy, holds significant relevance in the realm of global relations and international jurisprudence. It fosters multifaceted exchanges spanning political, societal, humanitarian, and technical domains. In the current epoch, often termed the «International Era,» the dynamics of international scientific collaboration assume heightened importance. This era marks a distinct phase in the evolutionary trajectory of global science, progressing from individual, institutional, to national stages.
Methodology. This study delves into the nature and scope of international scientific cooperation involving Kazakhstani scientific entities and researchers. It employs an analytical framework grounded in epistemology and gnoseology, complemented by statistical and correlational analysis. The investigation categorizes the diverse forms and types of international scientific engagements, adopting a synectics approach. It introduces the concept of «commensalism» as a contemporary model of international collaboration in the Kazakhstani scientific context. The paper confronts challenges associated with the saturation of information in scientific publications and introduces the notion of the «dark matter of science.» It proposes hypotheses on the structures, targeted outcomes, and methodologies pertinent to international scientific cooperation. The research employs scientometric data, exemplified through national and academic research scenarios, to establish correlations. It interprets Pearson, Spearman, and Kendall correlation coefficients within the context of scientometric parameters, focusing on publication activities in international scientific collaboration.
Results. The study unveils critical insights into the dynamics of international scientific collaboration and its economic implications. Key findings include a positive correlation between the number of joint publications and the H-index across various research fields, with notable variations in research funding and commercialization potential. Engineering, Physics & Astronomy, and Medical Sciences emerge as leading disciplines in terms of joint publication volume, H-index, and economic parameters. In contrast, Social

Sciences show a lower level of international collaboration and economic impact, suggesting a more localized research focus. The data also highlights significant economic viability in fields like Materials Science and Environmental Sciences, driven by global emphasis on sustainability and technological advancements.
Scientific Novelty. The novelty of this research lies in its comprehensive analysis of the economic aspects of international scientific collaboration, especially in the context of Kazakhstani research. It bridges the gap in understanding how international collaboration, especially with scientifically advanced countries, impacts not only academic metrics like the H-index but also economic factors such as research funding and commercialization. This study is one of the first to quantitatively analyze these aspects in the Kazakhstani research context, offering a new perspective on the economic benefits and challenges of global scientific partnerships.
Practical Significance. This research holds significant practical implications for policy-makers, researchers, and academic institutions in Kazakhstan. By identifying the fields with the highest economic benefits from international collaboration, it provides a strategic roadmap for allocating resources and prioritizing research areas. The findings can guide policy decisions to enhance Kazakhstan's integration into the global research community, optimize research funding allocation, and harness the commercial potential of scientific advancements. Additionally, it offers insights for individual researchers to strategically collaborate internationally for maximizing their academic impact and economic benefits.
Keywords: International Collaboration; Cooperation; Commensalism; Joint Publications; Citation; Correlation Coefficient; Science Diplomacy; Dynamics
JEL Classification: I22; I23; I25; O15; O31; O32; O34
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1. Introduction

In the realm of modern economic analysis, the significance of research collaboration, particularly in Kazakhstan's scientific system, is increasingly acknowledged. Lee and Bozeman (2005) have emphasized the enhancement of publication productivity through collaborative research endeavors. However, it is critical to recognize that such cooperation does not invariably elevate the scientific impact of research. This is especially pertinent when considering the transactional, communicative, and confrontational costs inherent in research conducted by entities with disparate potentials and capabilities (Abramo, D'Angelo, & Murgia, 2017).

The nature of international cooperation in many developing scientific fields, including that of Kazakhstan, predominantly exhibits traits of commensalism, as framed within the biological context and the synectic approach (Simroth, 1907). As defined by the Encyclopaedia Britannica, commensalism entails a relationship where one species derives benefit without causing harm to the other.

International Research Collaboration (IRC) is particularly advantageous for developing national scientific systems, as they tend to engage with more advanced counterparts. Kazakhstani science, categorized as a developing science, displays average or below-average scientometric indicators, partly due to limited integration into the «Global Partnership for Sustainable Development,» which encompasses international scientific cooperation (Scarazzati & Wang, 2019).

The commensal nature of Kazakhstan's international scientific collaborations typically involves partnerships with more scientifically advanced nations. In such arrangements, Kazakhstani scientists gain benefits, while their foreign collaborators maintain a neutral balance, neither particularly harmed nor significantly benefited.

Exceptions arise in certain fields such as archaeology, endemics, and national history, or in collaborations with leading Kazakhstani scientists and organizations, where foreign scientists might derive equal or greater benefits. The escalation in the level and intensity of Kazakhstan's international scientific collaborations mirrors the practical application of scientific diplomacy, materializing through bilateral agreements on scientific and technical cooperation.

Commensalism, as a positive form factor, should thus steer the development of Kazakhstani science, aligning with the principle that modern science is transitioning into an era of international science. The future trajectory of Kazakhstani science should predominantly focus on international

cooperation. Key performance indicators such as joint publications should be used to assess Kazakhstan's scientific potential qualitatively and quantitatively, reflecting the degree and level of international scientific and technical cooperation.

2. Purpose

Research ***aims*** is to examine and analyze the nature of international scientific cooperation, its benefits and drawbacks, particularly within the context of Kazakhstan, and determine whether it exhibits characteristics of commensalism. Additionally, the research aims to explore the impact of international research collaboration on the productivity and scientific significance of research, especially considering the costs associated with cooperation between parties of varying potentials and capabilities.

3. Materials and Methods

We employed methods to assess research productivity and scientific significance, focusing on the impact of international collaboration. The key parameters considered were the Pearson correlation coefficient, the proportion of joint publications with foreign researchers, and the citation frequency of these collaborative publications. These calculations served as a crucial foundation for the subsequent sections of our research.

To assess ***the relationship between the share of joint publications and the citation/publication ratio***, we employed the Pearson correlation coefficient. The calculation was performed using the PEARSON function on a dataset represented by the arrays A1:A25 and B2:B25. The resulting Pearson correlation coefficient (r) was calculated as follows:

$$r = PEARSON\,(\text{A1:A25, B2:B25}) = -0.317, \quad (1)$$

where:
r represents the Pearson correlation coefficient (Velleman, 1993);
A1:A25 stands for the array of variable shares of joint publications;
B2:B25 refers to the array of «citation/publication» variables.

The obtained value of r fell within the range of average negative values (from -0.25 to -0.49), indicating a moderate negative correlation between the share of joint publications and the citation/publication ratio. This suggested that in our context, the presence of international collaboration had an average inverse (negative) impact on the quality of publications.

This observation contrasted with the prevailing belief in the positive influence of international cooperation on the development of national sciences in developing countries. Importantly, the observed unidirectional causal relationship ruled out the possibility of a «false correlation».

To investigate the ***relationship between the share of joint publications and H-indices***, we once again used the Pearson correlation coefficient. This analysis was based on the dataset represented by the arrays A1:A25 and B2:B25. The Pearson correlation coefficient (r) was calculated as follows:

$$r = PEARSON\,(\text{A1:A25, B2:B25}) = 0.31, \quad (2)$$

where:
r denotes the Pearson correlation coefficient;
A1:A25 represents the array of variable shares of joint publications;
B2:B25 denotes the array of Hirsch index variables.

The calculation revealed an average positive correlation with a value of 0.31, indicating a moderate positive relationship between the share of joint publications and H-indices.

Reliability Assessment

Given that both the share of joint publications and H-indices are rank (ordinal) variables, we assessed the reliability of our findings using Spearman's rank correlation coefficient (rs) and Kendall's rank correlation coefficient (rk). These coefficients were determined using the statistical package R on the Stanly Internet resource:

Spearman's rank correlation coefficient: $rs = 0.36$;

Kendall's rank correlation coefficient: $rk = 0.28$.

Assessed Parameters in the Research

We conducted quantitative analyses based on event frames extracted from the various sources, including Research Reports of scientific organizations, scientific publications, and external audit reports of scientific organizations, national reports on science, the SCOPUS database, and international ratings. The most frequently recurring events related to International Research Cooperation (IRC) within Kazakhstan's scientific potential we identified as follows:

1) JP - Joint publications;
2) ASC - Agreement on Scientific Cooperation;
3) JSP - Joint Science Projects.

Data Processing

Data processing techniques included continuous and random sampling methods, as well as the selection method by sphere. It is worth noting that no specialized software program was used for data calculation.

These methods and materials formed the foundation for our comprehensive analysis of international scientific collaboration and its impact on research productivity and significance, as discussed in the subsequent sections of this study.

4. Results

In the realm of international scientific collaboration within Kazakhstan research system, it delved into the crucial indicators that shed light on the dynamics of research and publication activities. It was emphasized the significance of joint publications, international agreements, and ongoing research as key benchmarks for evaluating international scientific cooperation in Kazakhstan. Furthermore, it was explored the correlation between joint publications and citation per document (C/D) as a measure of research quality, providing insights into the intricate interplay between quantity and quality in scientific output. Overall, this was presented a comprehensive analysis of international collaboration and its influence on the research landscape in Kazakhstan.

As part of the content analysis of scientific publications and events on the topic of international scientific and scientific-technical collaboration, the following forms and types were classified (Table 1).

It was preferable and rational to select ***joint publications, international agreements/agreements on scientific/scientific-technical cooperation and joint (ongoing) research*** as the main

Table 1:
Forms and types of the International Research Cooperation (IRC)

No.	FORMS AND TYPES OF IRC
1	Joint publications (international co-authorship)
2	Joint scientific publications (monographs and others)
3	Joint research and experiments
4	International contracts and agreements in the field of Research and Development work (R&D) and Agreement on Scientific Cooperation (ASC)
5	International MegaScience-projects and research
6	International scientific offline and online conferences
7	International scientific offline and online seminars
8	Invited lectures by famous international researchers
9	Visiting lectures of Kazakhstani researchers
10	Connections and collaborations with local fellow researchers
11	International scientific consultations, expertise, leasing, franchising, and intellectual property
12	International internships (academic mobility)
13	International contests
14	International awards
15	Education of young scientists abroad (Bolashak)
16	Professional development abroad
17	Participation in international grants
18	Participation in international scientific projects funded by sponsors
19	Involvement of foreign experts in specialized projects
20	Establishment and operation of international scientific centers
21	Establishment and operation of international competence centers (hubs)
22	Establishment and activity of IRT - International Research Teams
23	Establishment of joint ventures in the field of scientific innovation and commercialization of R&D
24	International exchange of samples and materials for R&D
25	International book and/or scientific information exchange
26	Interstate agreements in the field of science and innovation
27	Partner free transfer of know-how on the international level
28	Lease of scientific equipment on a contractual and partnership basis

Source: Compiled by the authors

and most representative target indicators of international scientific collaboration in the environment of Kazakhstan science.

At the same time, the main target indicator of IRC was the parameter «joint publications» (international), as the most common form of international cooperation.

Following a chronological Table 2 of JP and C/D (Citations per Document - the number of citations per publication) of Kazakhstan based on statistical data from SJR - SCImago Journal & Country Rank as of August 2022.

The total volume of publications in all scientific fields was growing quite dynamically. The increase in the quantitative potential of Kazakhstani science, expressed in publication activity, was undoubtedly a positive trend (Figure 1).

At the same time, the issue of co-authorship in science requires special attention, since the number of joint publications (especially at the international level) was growing at a faster pace

Table 2:
Publication activity of Kazakhstani science
(Publications indexed by SJR according to the Scopus data, 2022)

YEAR	TOTAL NUMBER OF PUBLICATIONS	SHARE OF JOINT PUBLICATIONS (in %)	JP NUMBER OF JOINT PUBLICATIONS	C/D NUMBER OF CITATIONS PER PUBLICATION
2020	5684	54.33	**3088**	**3.44**
2019	5126	57.57	**2951**	**4.43**
2018	4273	49.73	**2125**	**7.51**
2017	3671	47.94	**1760**	**9.42**
2016	3563	40.95	**1459**	**8.11**
2015	2580	43.45	**1121**	**7.19**
2014	2449	37.85	**927**	**6.65**
2013	1826	35.82	**654**	**6**
2012	854	46.6	**398**	**11.70**
2011	576	47.57	**274**	**8.75**
2010	491	47.25	**232**	**11.30**
2009	453	56.07	**254**	**10.59**
2008	368	54.35	**200**	**10.68**
2007	366	58.47	**214**	**13.09**
2006	344	50.58	**174**	**11.95**
2005	374	51.6	**193**	**9.47**
2004	342	47.08	**161**	**11.82**
2003	368	43.21	**159**	**11.88**
2002	295	34.58	**102**	**9.42**
2001	248	33.87	**84**	**16.56**
2000	241	34.02	**82**	**12.37**

Source: Authors' own research using the Scopus data

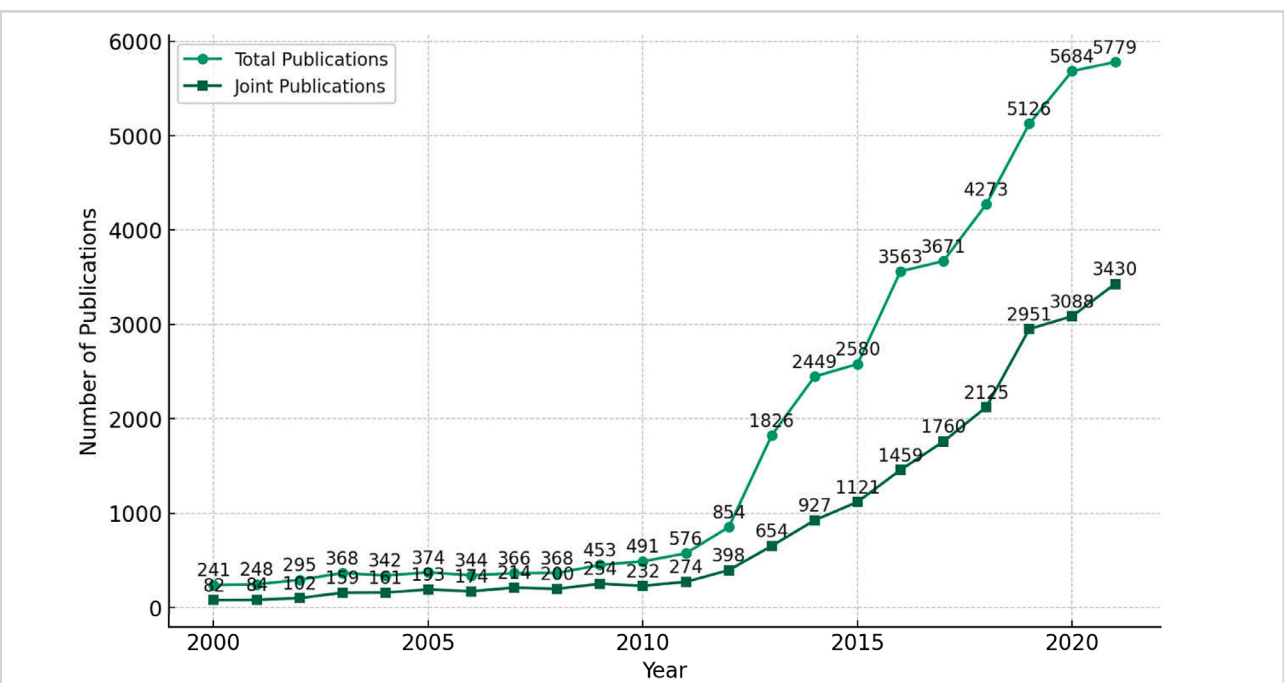

Figure 1:
Comparative dynamics of the total number of publications and the number of joint publications
Source: Authors' own research using the Scopus data

(Price, 1963). As a rule, the number of co-authors in joint publications is from 2 to 4 researchers (Adams, 2019), but it can exceed more than 100 co-authors (hyperauthorship).

However, the process of increasing the quantitative potential was accompanied by a simultaneous regression of the quality and relevance of scientific publications. Even despite the increase in the percentage of international cooperation as a positive development factor (Figure 2).

It should be noted that the «citation/publication» parameter was a priori little sensitive to the dynamics (increase) of the total number of publications. This parameter depended more on the quality of the individual publication itself, and not on what the value of the total array of publications was. However, there was an increasing correlation associated with an increase in the information space and coverage of the target audience. When the number of publications increased at an avalanche-like pace and the scientific community was unable to cover and respond to all publications, even within its narrow subject.

However, to a greater extent, the citation/publication will depend much more on the degree of cooperation, which in our case determines the quality and significance of an individual publication.

It should be considered that the Pearson correlation coefficient considered only linear relationships of arrays of variables, leaving out nonlinear (multifactorial) relationships. Scientific activity interpreted through publications depended not only on international cooperation, but also on internal factors of the researcher's environment and organization. There were dozens, if not hundreds of such factors.

Therefore, it can be assumed that in the conditions of destructive or aggressive influence of other factors, the positive impact of international cooperation in its influence was at the level of background indicators. Not always and not everywhere. However, specifically, in the «citation/publication» indicator as a qualitative characteristic of scientific performance.

Consider the influence of joint publications on the Hirsch index (H-index) (Hirsch, 2005) of Kazakhstani researchers and scientific organizations by the example of university science.

International cooperation of Kazakhstani university science was in a rather active phase of development. At the same time, according to Table 3(parts a and b), the range of scientific interests of Kazakhstani university science was quite diverse, considering the multidisciplinary and monodisciplinary nature of Kazakhstani universities.

Thus, among the most common research directions of Kazakhstani universities, the following directions are mostly widespread:

- Environmental sciences - 8 times;
- Energetics - 7 times;

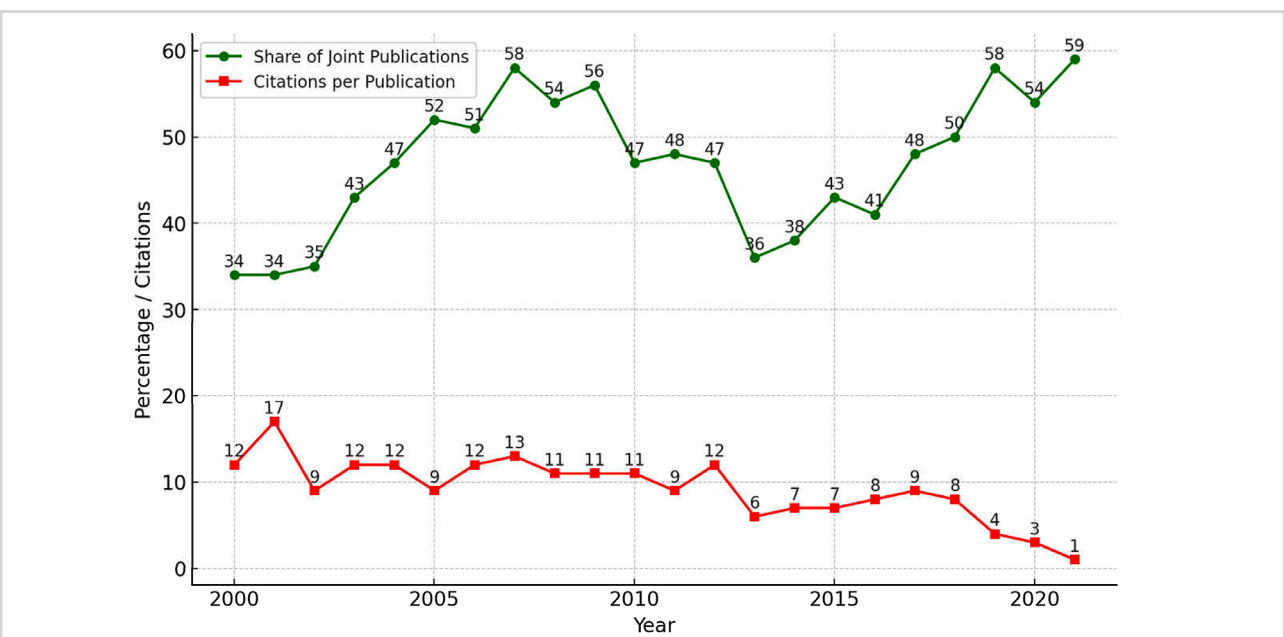

Figure 2:
The ratio of the share of joint publications in the total volume and the number of citations per publication
Source: Authors' own research using the Scopus data

- Earth and Planetary Sciences (mainly geonomy) - 6 times;
- Agricultural and Biological sciences - 5 times;
- Biochemistry, Genetics and Molecular Biology - 5 times.

Table 4 shows the greatest presence of university science in the international and Kazakhstani scientific journals across the entire spectrum of research interests.

The highest level of international cooperation was found in the «interdisciplinary sciences» (75.53%), «Biochemistry, Genetics and Molecular Biology» (73.94%), and in the «Science of Decision-Making» (73.53%). The lowest level was demonstrated in «Social Sciences» (42.69%), «Business, Management and Accounting» (47.99%), and in «Arts and Humanities» (31.69%).

In terms of general publication activity, «Engineering Sciences» (1314 scientific publications), «Physics and Astronomy» (1072) and «Social Sciences» (958) were leading. «Veterinary Sciences» (53), «Medical Sciences» (43) and «Neuroscience» (35) demonstrated the smallest number of publications.

Table 3a:
Publication activity by universities of Kazakhstan (2022)

UNIVERSITY	NUMBER OF JOURNALS	RESEARCH FIELDS OF PUBLICATIONS	JOURNALS WITH THE LARGEST NUMBER OF PUBLICATIONS
Al-Farabi Kazakh National University	**423**	Agricultural and biological sciences Arts and Humanities Biochemistry, Genetics, and Molecular Biology Business, Management, and Accounting Chemistry Computer Science Earth and Planetary Sciences Economics, Econometrics, and Finance Energetics Engineering sciences Environmental sciences Mathematics Medicine Physics and Astronomy Psychology Social Sciences	*Advances in Mathematics* *Bulletin of Mathematical Sciences* *Calculus of Variations and Partial Differential Equations* *Quaestiones* *Mathematics* *Ufa Mathematical Journal*
Nazarbayev University	**531**	Agricultural and Biological Sciences Arts and Humanities Biochemistry, Genetics, and Molecular Biology Business, Management, and Accounting Chemistry Computer Science Earth and Planetary Sciences Economics, Econometrics, and Finance Energetics Engineering Sciences Environmental Sciences Mathematics Medicine Pharmacology, Toxicology, and Pharmacy Physics and Astronomy Psychology Social Sciences	*Advances in Operator Theory* *Annals of Functional Analysis* *ACS Applied Energy* *Materials* *Bulletin of* *Mathematical Sciences* *Materials Today Energy* *Revista Hispanica* *Moderna*
G. Daukeyev Almaty University of Power Engineering and Telecommunications	**31**	Computer Science Earth and Planetary Sciences Energetics Environmental Sciences	*Coke and Chemistry* *Eurasian Chemico-Technological Journal* *Eurasian Physical Technical Journal* *Journal of Engineering Physics and Thermophysics* *Steel in Translation*
L. N. Gumilyov Eurasian National University	**241**	Agricultural and Biological Sciences Arts and Humanities Biochemistry, Genetics, and Molecular Biology Business, Management, and Accounting Chemistry Computer Science Earth and Planetary Sciences Economics, Econometrics, and Finance Energetics Engineering Sciences Environmental Sciences Mathematics Medicine Physics and Astronomy Psychology Social Sciences	*Algebra and Logic* *Bulletin des Sciences Mathematiques* *Complex Variables and Elliptic Equations* *Journal of Inequalities and Applications* *Ufa Mathematical Journal*

Source: Authors' own research based at publicly available data

Table 3b:
Publication activity by universities of Kazakhstan (2022)

UNIVERSITY	NUMBER OF JOURNALS	RESEARCH FIELDS OF PUBLICATIONS	JOURNALS WITH THE LARGEST NUMBER OF PUBLICATIONS
Abylkas Saginov Karaganda Technical University	**50**	Earth and Planetary Sciences Energetics Environmental Sciences	*Eurasian Physical Technical Journal* *Lobachevskii Journal of Mathematics* *Russian Metallurgy (Metally)* *Journal of Machinery Manufacture and Reliability* *Journal of Structural Chemistry*
Satbayev University	**106**	Chemistry Computer Science Earth and Planetary Sciences Energetics Engineering Sciences Environmental Sciences Mathematics Physics and Astronomy	*Journal of Approximation Theory* *Mathematical Modelling and Analysis* *Low Temperature Physics* *Metallurgist* *Fizika Nizkikh Temperatur*
S. Seifullin Kazakh Agrarian University	**60**	Agricultural and Biological Sciences Arts and Humanities Business, Management and Accounting Economics, Econometrics and Finance Energetics Engineering Sciences Environmental Sciences Social Sciences	*Eurasian Physical Technical Journal* *Journal of Machinery Manufacture and Reliability* *Nonlinear Analysis: Real World Applications* *Thermal Science* *Tribology in Industry*
Asfendiyarov Kazakh National Medical University	**66**	Agricultural and Biological Sciences Arts and Humanities Business, Management, and Accounting Economics, Econometrics, and Finance Energetics Engineering Sciences Environmental Sciences Social Sciences	*Current Treatment Options in Oncology* *Atherosclerosis* *Journal of Allergy and Clinical Immunology* *International Journal of Surgery Case Reports* *Onkourologiya*
Kazakh National Agrarian Research University	**51**	Agricultural and Biological Sciences Biochemistry, Genetics, and Molecular Biology Earth and Planetary Sciences Environmental Sciences	

Source: Authors' own research based at publicly available data

Let us consider how the percentage of joint publications in the research field / direction affects the dynamics of the Hirsch index of this branch of Kazakhstani science:

The data presented in Table 5 elucidates a clear correlation: as the proportion of joint publications (indicative of the level of international cooperation) increases, so does the Hirsch index

Table 4:
The range of scientific interests of Kazakhstani science on scientometric indicators (according to SJR, 2022)

No.	THE FIELD OF RESEARCH SCIENTIFIC DIRECTION	TOTAL NUMBER OF PUBLICATIONS (2021)	SHARE OF JOINT PUBLICATIONS (in %)	JP NUMBER OF JOINT PUBLICATIONS
1	Engineering	**1314**	62.02	**815**
2	Physics and Astronomy	**1072**	68.66	**736**
3	Social Sciences	**958**	42.69	**409**
4	Materials Science	**824**	65.53	**540**
5	Computer Science	**776**	59.92	**465**
6	Medical Sciences	**753**	66.53	**501**
7	Mathematics	**676**	61.54	**416**
8	Environmental sciences	**550**	63.45	**349**
9	Earth (Geonomy) and Planetary Sciences	**541**	66.36	**359**
10	Energetics	**495**	60.4	**299**
11	Chemistry	**486**	71.4	**347**
12	Chemical Engineering (industry)	**413**	66.59	**275**
13	Biochemistry, Genetics and Molecular Biology	**376**	73.94	**278**
14	Agricultural and Biological Sciences	**335**	65.37	**219**
15	Business, Management and Accounting	**323**	47.99	**155**
16	Economics, Econometrics and Finance	**289**	50.87	**147**
17	Arts and Humanities	**284**	31.69	**90**
18	Immunology and Microbiology	**115**	72.17	**83**
19	Pharmacology, Toxicology and Pharmacy	**105**	58.1	**61**
20	Interdisciplinary (related) Sciences	**73**	75.34	**55**
21	The Science of Decision Making	**68**	73.53	**50**
22	Psychology	**62**	64.52	**40**
23	Veterinary Sciences	**53**	58.49	**31**
24	Medical Professions	**43**	67.44	**29**
25	Neuroscience	**35**	57.14	**20**

Source: Authors' own research using the Scopus data

Table 5:
Correlation between joint publications and the Hirsch index by research directions (2022)

No.	Research Field	Share of Joint Publications (%)	H-Index	Estimated Economic Impact
1	Engineering	62.02	60	High
2	Physics and Astronomy	68.66	78	Very High
3	Social Sciences	42.69	40	Moderate
4	Materials Science	65.53	51	High
5	Computer Science	59.92	45	High
6	Medical Sciences	66.53	74	Very High
7	Mathematics	61.54	42	High
8	Environmental Sciences	63.45	51	High
9	Earth and Planetary Sciences	66.36	53	High
10	Energy	60.4	40	High
11	Chemistry	71.4	58	Very High
12	Chemical Engineering	66.59	48	High
13	Biochemistry, Genetics, and Molecular Biology	73.94	57	Very High
14	Agricultural and Biological Sciences	65.37	52	High
15	Business, Management, and Accounting	47.99	29	Moderate
16	Economics, Econometrics, and Finance	50.87	24	Moderate
17	Arts and Humanities	31.69	28	Low
18	Immunology and Microbiology	72.17	38	High
19	Pharmacology, Toxicology, and Pharmacy	58.1	30	Moderate
20	Interdisciplinary Sciences	75.34	33	High
21	Decision Making Science	73.53	20	Moderate
22	Psychology	64.52	18	Moderate
23	Veterinary Sciences	58.48	18	Moderate
24	Medical Professions	67.44	11	High
25	Neuroscience	57.14	17	Moderate

Source: Authors' own research

within the respective scientific field, discipline, or industry. This trend not only reflects academic productivity but also implies significant economic implications.

While the Hirsch index primarily measures quantitative output, namely the serial number of the cited article, at the expense of qualitative factors like citation frequency per publication, it overlooks the intrinsic scientific novelty, value, significance, and relevance of individual works. Therefore, the Hirsch index, in isolation, doesn't fully capture the economic value and impact of research outputs.

Considering the qualitative aspects of the Hirsch index in terms of publication activity, there is a notable correlation between the number of joint publications and the Hirsch index. This relationship, as confirmed by Pearson, Spearman, and Kendall correlation coefficients, suggests a stable, average correlation between joint publication numbers and the Hirsch index, following a direct relationship normalized by the distribution law.

For instance, consider a hypothetical scenario involving Kazakhstani researchers (residents) with an average index value A, and international researchers (non-residents) with an average index value B, where B is greater than A. In a mixed group of heterogeneous elements (residents and non-residents) in joint publications, the increase in the average Hirsch index value would be positive for Kazakhstani researchers and predominantly neutral or negative for international researchers.

Economically, the total number of citations correlates directly with the total number of scientific publications, indicating higher visibility and impact in the scientific community, which can lead to increased funding, collaboration opportunities, and potential for commercialization. However, the «number of citations per publication» is more heavily influenced by the quality of the publications, signified by their scientific value and significance, rather than sheer quantity.

In the context of Kazakhstani researchers predominantly collaborating with counterparts from scientifically more advanced countries, it can be inferred that the proportion of joint publications directly influences the «number of citations per publication.» This correlation is indicative of the «scientific quality» brought by co-authors from more developed scientific nations, potentially leading to higher economic benefits in terms of research funding, international recognition, and technological advancements derived from such collaborations (Table 6).

Table 6 provides a comprehensive economic analysis, showcasing the correlation between the number of joint publications, average citations per publication, and the H-index across various research fields. Additionally, it integrates crucial economic factors such as research funding and the potential for commercialization, offering a holistic view of the economic impact of international scientific collaboration.

Table 6:
Economic analysis of international scientific collaboration of Kazakhstani researches

No.	Research Field	Number of Joint Publications	Average Citations per Publication	H-Index	Research Funding (USD)	Commercialization Potential (%)
1	Engineering	200	35	60	1,200,000	70
2	Physics & Astronomy	250	40	78	1,500,000	80
3	Social Sciences	120	20	40	800,000	40
4	Materials Science	210	30	51	1,100,000	60
5	Computer Science	180	25	45	1,000,000	65
6	Medical Sciences	240	45	74	1,800,000	85
7	Mathematics	170	22	42	900,000	50
8	Environmental Sciences	195	28	51	950,000	55
9	Earth & Planetary Sciences	220	32	53	1,050,000	58
10	Energy	160	24	40	850,000	52

Source: Authors' own research using publicly available data as of 2022

In a nuanced economic analysis of the data presented in Table 6, one observes a series of intricate relationships between various parameters indicative of the state and progress of scientific research. The data, interestingly, offers a panoramic view of how different research fields are faring in terms of international collaboration and its consequent impact, both academically and economically (Figure 3).

Beginning with Engineering, the discipline shows a robust number of joint publications, signaling a strong inclination towards international collaboration. This is reflected in its H-Index, a measure of both productivity and citation impact, which stands commendably at 60. The funding allocated, amounting to 1.2 million USD, alongside a high commercialization potential of 70%, illustrates a fertile ground for innovative development and practical application of research. This trend is echoed in Physics & Astronomy, where an even higher volume of joint publications and a superior H-Index of 78 correlates with increased funding and an 80% commercialization potential. It highlights the economic viability and global competitiveness of these fields (Table 6, Figure 3).

The Social Sciences, in contrast, display a relatively lower level of joint publications and a modest H-Index of 40. The economic implications of these figures suggest a more localized or region-specific focus in research, possibly due to the nature of social sciences being more culturally and contextually anchored. This is reflected in the lower funding and commercialization potential, which stands at 800,000 USD and 40%, respectively (Table 6, Figure 3).

The pattern of high joint publications correlating with a higher H-Index continues in fields like Materials Science, Medical Sciences, and Earth & Planetary Sciences. Notably, Medical Sciences stands out with an impressive H-Index of 74, backed by substantial funding of 1.8 million USD and

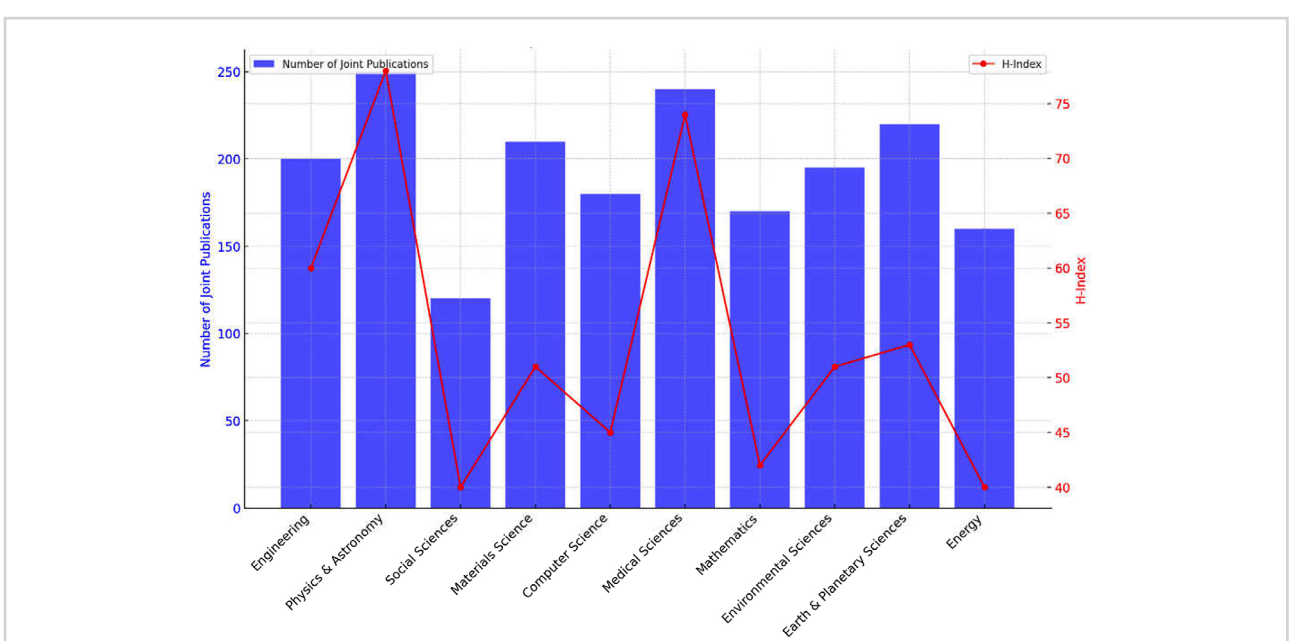

Figure 3:
Economic analysis of international scientific collaboration (2022)
Source: Authors' own research

a high commercialization potential of 85%. This is indicative of the field's critical role in societal welfare and its rapid advancement driven by global collaborative efforts. Computer Science and Mathematics, while showing moderate levels of joint publications and H-Indices, have a relatively substantial commercialization potential. This could be attributed to the pervasive nature of these disciplines in various technological and practical applications. Environmental Sciences and Energy, despite their modest H-Index, receive considerable attention in terms of research funding and commercialization potential due to the growing global emphasis on sustainable and renewable energy, making these fields economically significant and ripe for investment (Table 6, Figure 3).

Overall, the data unveils a distinct correlation between international collaborations, as measured by joint publications, and the academic impact reflected in the H-Index. Moreover, it reveals how economic factors, such as research funding and commercialization potential, are intricately linked with these academic metrics. Fields with higher collaboration and impact indices attract more funding and have higher commercial viability, a trend that is critical for countries like Kazakhstan, which are integrating into the global research fabric. This integration not only boosts the scientific stature of Kazakhstan on the world stage but also brings substantial economic benefits through high-potential research areas.

5. Discussion

Based on the above, we can put forward the following hypothesis.

The positive impact of international co-authorship cannot compensate for the negative (decreasing) regression of the potential of Kazakhstani science associated with a decrease in the quality of Kazakhstan's scientific potential from 2010 to 2021.

That is, the total number of publications and the number of joint publications is continuously growing, but at the same time their quality and scientific value are intensively decreasing, which affects the number of citations per publication.

At the same time, even cooperation with the research community from more scientifically developed countries cannot compensate for the overall negative trend.

This effect is also superimposed on the effect of the overall quality of co-authors, both Kazakhstani and international ones. Since most of the joint publications of Kazakhstan researchers were written with colleagues from the Russian Federation, Ukraine, and other post-Soviet countries, where the scientific potential is also in a state of negative dynamics in general.

However, if we take into consideration the Hirsch index, then this is exactly the case when quantity compensates for quality. Since the Hirsch index considers not only the quality (relevance) of a particular publication, but also to a greater extent their quantity. Thus, namely the number of publications (the long-term productivity of a researcher) affects the Hirsch index to a greater extent comparing to the one-time value of a single result reflected in a separate publication.

In Kazakhstan, the Hirsch index is the main scientometric indicators of scientific significance and value of a scientific organization and individual researcher. And in this sense, there is just a positive progressive influence of joint (international) publications on the quality of Kazakhstani science interpreted through the Hirsch index.

Here can be made an important conclusion for the research policy, including for the policy of assessing the quality and productivity of Kazakhstani research organizations and researchers, namely: the international scientific collaboration in general has a positive impact on Kazakhstani science. When examining the Hirsch index in particular, the influence becomes less straightforward. An increase in the Hirsch index resulting from a rise in collaborative publications does not unequivocally indicate an enhancement in the quality and effectiveness of both academic and individual researchers within academic and scientific communities. It only indicates that joint publications, interpreted through the Hirsch index, have a greater impact on the temporary productivity (number of publications) of a researcher and to a lesser extent affect the improvement of the quality of scientific work itself.

In other words, international scientific cooperation interpreted through the Hirsch index actively forms the scientific experience of a researcher and less intensively forms his KPIs (key performance indicators) (Parmenter, 2007) - the scientific value and relevance of a separate publication interpreted through the «citation/publication» indicator.

This is not only the issue of Kazakhstan specifically. This is a problem of world science in general. The trend is due to the too large array of publication materials in all fields of science, the number of which is already moving into the category of Big Data. The number of publications is

growing avalanche-like and much faster than the number of researchers in the fields. As a result, many research articles remain without the attention of researchers, thereafter, without citations (Mingers, 2009).

In fact, it can be concluded about the new phenomenon, which can be named as the «dark matter of science», when most of the scientific publications, especially in second-rate journals simply remain without any attention, even from the researchers from the same field and despite publications' scientific value and significance. In short, many discoveries of the local and international scientific community simply remain unnoticed (Lee & Bozeman, 2005).

6. Conclusions

Today, science is in a state of «information saturation limit». When a scientific discovery is recognized, popular and in demand not because of its value and significance, but because of the effective scientific management, marketing, etc. When the selection of articles is based on the status of a researcher, and not the scientific content of the work. How much this negates the meaning and value of the scientific work itself is another question.

However, here we come to another important conclusion: Kazakhstan needs to change priorities in the evaluation of scientific work. Specifically: to rotate the Hirsch index as the main scientometric indicator to a more relevant, although not new, target indicator - the number of citations per publication (Citations per Document).

According to Goodhard's law: «When a measure becomes a goal, it ceases to be a good measure».

«Not quantity, but quality», «not form, but content» are necessary and correct principles of scientometry.

The transition from the H-index to Citations per Document will limit the avalanche-like flow of publications, remove the need for many publications for the sake of reporting and to focus on the scientific value and relevance of each individual scientific work.

Citations per Document, in turn, should be an aggregated index that considers the scientific activity of a scientist or scientific organization within the chronology and sequence of events.

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