# “Modeling of publication performance using a system dynamics approach: Evidence from Kazakhstan”

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# MODELING OF PUBLICATION PERFORMANCE USING A SYSTEM DYNAMICS APPROACH: EVIDENCE FROM KAZAKHSTAN

**Abstract**

Scientific productivity is one of the key benchmarks to evaluate the development of a country in terms of innovation potential and competitiveness in the global academic environment. This study investigates the impact of key factors such as faculty workload and satisfaction, career dynamics, institutional environment, and research funding on publication performance. The methodology is based on system dynamics (SD), a simulation approach that assesses the dynamic impact of multiple factors on the publication performance. The approach combines causal-loop analysis, stock-and-flow diagrams, sensitivity testing, and Monte Carlo simulations, with Kazakhstan serving as a case country. The data on the factors, including from the global literature and statistics from Kazakhstan, were simulated to forecast publication performance and research output through 2030. Sensitivity analysis identified six dominant factors affecting the number of researchers: average wage growth rate, Ph.D. growth rate, average author tenure, normal workload, job satisfaction, and productivity rate. In contrast, the number of publications was most influenced by the research expenditure per paper, government investment growth rate, and private sector investment growth rate. The study findings from Kazakhstan can serve as "lessons learned" and assist researchers and policymakers working in the science policy and evaluation area in identifying high-impact factors and formulating more effective strategies to enhance the scientific knowledge creation of a country.

**Keywords** research productivity, research infrastructure, science, science evaluation, scientific environment, knowledge production

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## INTRODUCTION

In recent years, publication performance has become a key benchmark for assessing the development of countries in terms of innovation potential and competitiveness in the global academic environment. Publication performance of a country is defined as the total number of publications (e.g., journal articles) that scholars contribute to an overall knowledge base within a specific time frame in a country (Heilig & Voß, 2015). It is one of the leading indicators that reflects not only the volume of publications but also the quality of published research, its visibility, and impact (Amirbekova et al., 2022; Jamali et al., 2024). Countries with universities and institutions which has stronger publication records are more likely to attract top faculty and funding, improve their academic reputation and global ranking, create innovation, and contribute to national development (Ghabban et al., 2019).

The literature shows that multiple factors impact the publication performance of a country. Some studies stated that individual factors (like job satisfaction, workload, and salary) had more impact on the publication performance. In contrast, others found that institutional



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factors (like availability of funding, research collaboration, tenure conditions) had a greater influence. Also, the literature shows that external factors relating to the national and international environment (financial, R&D spending, international collaboration) of a country determine the publication performance. This indicates a need for a deeper analysis of various factors that impact the publication performance and a search for tools to allow for its more comprehensive analysis and prediction. Kazakhstan is taken as a case country whose data are used to analyze the impact of such factors on the publication performance of the country.

The contributions of the current study are twofold. First, using real data, this study captures the relationship between key variables and publication performance as a measurable output of the scientific knowledge base. Second, using a system dynamics simulation approach, this study provides forecasting capabilities that present multiple scenarios of publication performance. The study findings can serve as "lessons learned" and assist researchers and policymakers working in the scientific knowledge creation and science evaluation areas in identifying high-impact factors and formulating more effective strategies to enhance the scientific knowledge production of a country.

## 1. LITERATURE REVIEW

The publication performance has been a central theme in the study of academic institutions and the academic reputation of countries. It is often used as a metric to evaluate academic success, institutional reputation, and the global standing of universities and entire nations.

Overall, the literature on research productivity and performance has been growing naturally, considering the development of science and technology since the middle of the 20th century. Price (1963) established a foundational explanation for the exponential growth of science and the cumulative nature of knowledge production. Later, J. Cole and S. Cole (1973) stated that the growing scientific production should be measured empirically using research indicators. They examined the sociology of scientific production, emphasizing that publication performance, as a research indicator, is not merely the quantity of output but is deeply embedded in academic norms, peer recognition, and disciplinary contexts.

Therefore, literature offers a range of factors that determine the scientific knowledge production. These factors range from internal, relating to individual and institutional contexts (faculty reputation, working conditions), to external, relating to national and international environment (financial, R&D spending, international collaboration) (Negash et al., 2019). For example, Merton (1968) empirically proved how more reputed researchers receive disproportionate credit, which perpetuates cycles of high publication productivity and recognition. This concept underscores cumulative advantage in academic careers. Other factors that determine the publication performance relate to working conditions in the academic environment. Dissatisfaction with working conditions, overwork, low pay, and an unfavorable administrative climate can reduce the motivation of scientists and limit their publication activity. The number of graduate students and young researchers involved in research projects also stands out among the key factors. Insufficient funding and high tuition fees can constrain the growth of the number of Ph.D. researchers, while their participation directly contributes to increased publication performance and quality (Menon et al., 2018). Forms of internal collaboration play an important role in enhancing publication activity. Internal interaction between the faculties and departments contributes to a more efficient use of resources (Abramo et al., 2009). Overall, at the institutional level, Dundar and Lewis (1998) analyzed how internal factors such as resources, faculty workload, and research culture affect productivity. They argued that faculty publication performance is contingent upon both individual capability and institutional support structures.

Other studies investigated external factors. Initial studies focused on the role of financing, particularly on the direct impact of private investment in R&D on innovation and publication activities (Karlsson et al., 2004). Subsequent studies have confirmed the existence of a positive relationship between investment in R&D and publication performance growth (Kancs & Silivertovs, 2016). Additionally, the effectiveness of publication performance is primarily determined by the structure of public investment in R&D (Ding et al., 2023). Also, various sources of funding, both internal and external, play a crucial role in maintaining a sustainable level of publication performance. These include investments through various programs, grants, and subsidies that support research initiatives (Graf & Kalthaus, 2018; Uyar et al., 2022). Another important aspect is foreign investment and external financing, which contribute to the transfer of knowledge, the expansion of international scientific collaboration, and the improvement of research efficiency, especially in developing countries (Zhang, 2017; Shkarupa et al., 2022). According to numerous studies, international collaboration has a significantly positive impact, especially for countries with emerging scientific capabilities (Vuong et al., 2019; Jamali et al., 2024). For example, co-authorship serves as an indicator of cooperation, and according to several studies, it positively correlates with the probability of publication in high-impact journals and the level of citations (Wamala & Ssembatya, 2015; Chatterjee et al., 2020; Panikarova et al., 2017). The relationship between academic experience and publication activity has also been confirmed: experienced researchers tend to have higher publication performance (Rørstad & Aksnes, 2015).

In terms of measuring publication performance, with the rise of scientometrics, bibliometric indicators have been used. Foundational studies by Garfield (1972), who proposed the impact factor, and Hirsch (2005), who proposed the h-index, provided standardized metrics to assess the influence of scientific knowledge and publication performance. Since then, bibliometric indicators including citation counts, impact factor, and h-index have become widely used, albeit with ongoing debates regarding their validity in capturing actual scholarly impact. Using these indicators, Bornmann and Mutz (2014) conducted a bibliometric analysis of scientific articles from the mid-1600s to 2012 and found exponential growth in the number of publications, while revealing an unfair distribution of citations, where newer publications were cited more often than older ones. To support this, Larivière et al. (2015) studied 44.5 million scientific papers from 1973 to 2012 and also noticed a steady increase in publications over this period. In particular, they attribute the rapid growth in publications to the development of digital technologies (since the mid-1990s). Green et al. (2002) also stated an acceleration in the publication rates during the 1990s, while noting that about 20.0% of doctoral researchers published over 40.0% of the articles.

Despite a wide range of studies devoted to the factors influencing publication performance, their systemic interrelationships remain insufficiently studied, as well as the dynamic effect of specific categories of factors (relating to individual working conditions, institutional environment, and national funding) on the overall publication performance. In this context, developing a modelling tool capable of quantifying the contribution of key factors to the publication performance and predicting future scenarios of scientific knowledge output is of critical importance. To achieve this, the study develops and validates a system dynamics (SD) model that integrates these factors into a unified framework, enabling both sensitivity analysis to identify the most critical drivers and Monte Carlo simulations to generate probabilistic forecasts. Kazakhstan is used as a case study to demonstrate the applicability of the model, while the approach itself is scalable and can be adapted to other national contexts.

The purpose of this study is to examine the impact of key factors, including faculty workload and satisfaction, career dynamics, institutional environment, and research funding, on publication performance.

## 2. METHODOLOGY

The present study uses the SD method, which models complex nonlinear relationships between influencing factors and publication performance. Next, each stage of the methodology is described in more detail so that the methodology can be replicated and adapted for application to other countries. To run the proposed SD model and conduct the sensitivity analysis and MC simulations, the software Vensim PLE Plus (Vensim, 2025) was uti-


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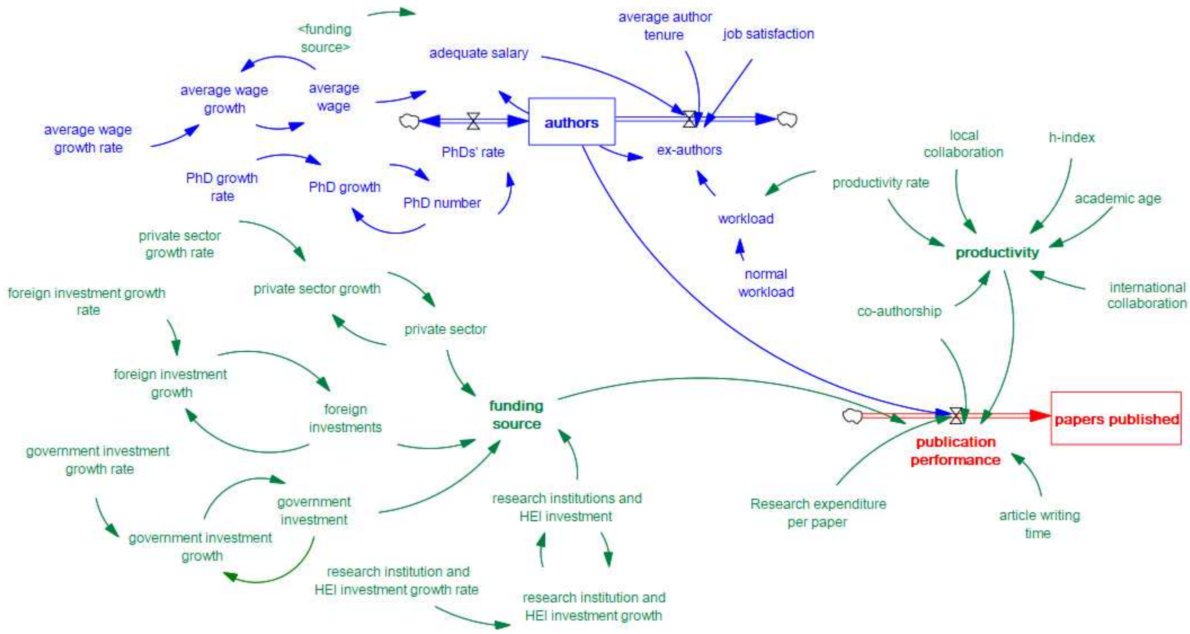


**Figure 1.** Factors affecting publication performance (SD modeling created)

lized. The methodology includes five stages: identification of the critical factors, the SD model design, data collection, sensitivity analysis and MC simulation, findings, and discussions.

In Stage 1, based on the results of the comprehensive literature review above, the study identified key factors that impact the publication performance. These were grouped into three categories: author-related, productivity-related, and funding-related factors. Appendix A provides a detailed list and description of these factors along with their primary sources.

In Stage 2, an SD model was developed to explore the influence of these factors on the publication performance. The model consists of two subsystems: one for Authors and the other for Papers published (Figure 1). It is noted that this proposed SD model in Figure 1 can be scaled up and adapted to other countries (using their specific data), thereby expanding the model's practical applicability for strategic planning in scientific knowledge production in other countries.

Each of the two subsystems, presented in Figure 1, contains stock variables and associated flows that reflect the accumulation and depletion of research capacity and output over time. SD is a quantitative approach that adds value to each variable such that a model with its loops, stocks, and flows can be analyzed to gain insights into the understanding of changes in an output factor (Samoilov et al., 2024a; Castelblanco et al., 2024a). A stock has an inflow of resources (represented with an incoming arrow on the left of the box) and an outflow of resources (represented with an outgoing arrow on the right of the box). It has two stocks, which are further regarded as subsystems in this paper: subsystems of Authors and Papers published. This model includes other variables that describe or mathematically define the main critical factors in the study. These variables were defined, and their data collection is presented in Stage 3 next.

In Stage 3, data collection was conducted. All the data on the variables such as the academic age, article writing time, co-authorship, h-index, international collaboration, job satisfaction, local collaboration, productivity, and workload were taken from the following sources (Abramo et al., 2009; Pastor et al., 2015; Rørstad & Aksnes, 2015; Wamala & Ssembatya, 2015; Vuong et al., 2019; Narbaev & Amirbekova, 2021; Jamali et al., 2024). The statistical data on Kazakhstan are taken from the following sources (NCSTE, 2020, 2023; BNSRK, 2024), which report the data till 2022. Therefore, for a complete and consistent analysis of all the factors, the data up to 2022 were considered.

In the subsystem Authors, the study extends the critical factors from Appendix A by adding additional variables with data on Kazakhstan. For this, real data values from Table 1 are assigned to the factors and variables. The stock Authors have an inflow variable, Ph.D. rate, and an outflow variable, ex-authors. The inflow variable Ph.D. rate is inflated by the Ph.D. numbers, which grow yearly. The outflow variable Ex-author depends on the following variables: job satisfaction, workload, adequate salary, and average author tenure. The Ex-authors are balanced by two variables: the average author tenure, which is limited according to national statistics to an average of 30 years (NCSTE, 2020, 2023), and the adequate salary of a researcher. In Figure 1, in turn, the adequate salary depends on the variable average wage, which is a salary outside academia and a funding source. The study posits that the salaries in academia are crucial and should not be lower than in other industries (Negash et al., 2019; Wamala & Ssembatya, 2015). These relationships are defined in the model through the variables with the values presented in Table 1.

The subsystem Papers published shows the level of the publication performance in Kazakhstan (Figure 1). Table 2 provides the list of its variables and their data. The factor group Productivity in Figure 1 contains a variety of constants that define the author's level of publication performance. These variables overall determine the research profile of a given author and their number, which can differ, and it can be challenging to develop an appropriate model that reflects research performance. Therefore, the quality and quantity of research activity and performance vary from institution to institution (Ding et al., 2023; Erkoc, 2015). Academic age, which is defined by research experience gained after receiving a Ph.D. degree, affects publication productivity, according to the study conducted by Rørstad & Aksnes (2015). The factor group Funding source relies on the 4 major sources of science funding. Without funding, it is challenging to realize the normal functioning of national research (Graf & Kalthaus, 2018). In the model, publication performance is affected by two other variables: the research expenditure per paper,-and the article writing time.

In Stage 4 of the study, a sensitivity analysis and MC simulation are conducted. The mean absolute deviation is chosen for this analysis, which can evaluate the impact of changes in input variables (Kleijnen, 1995; De Marco & Narbaev, 2021). In this study, the sensitivity analysis helps to determine which of the variables the publication performance is the most sensitive to. In other words, the research reveals which factors have the most significant influence on the level of the publication performance in Kazakhstan. This allowed the identification of high-impact factors driving author retention and publication output in the Kazakhstani research system.

Next, the MC simulation is used. It is based on computational algorithms that use extensive

**Table 1.** Variables in the subsystem (Authors)

Source: Authors.

| Variable | Initial values as of 2015, units | Description |
|---|---|---|
| Authors | 18,454; person | 18,454 authors |
| Inflow – Ph.D. rate | 794; person | The variable Ph.D. number directly impacts the annual Ph.D. student rate |
| Ph.D. number | 794; person | 794 Ph.D. Students were enrolled in 2015. The average annual growth rate from 2015 to 2022 is 0.10 |
| Outflow – Ex-authors | 295; person/year | The number of authors who cease to publish depends on three factors: the rate of pay outside of academia, workload, and overall career longevity |
| Job satisfaction | 1.5; dmnl | Where 1.0 means satisfied with the job, and 2.0 means dissatisfied with the job |
| Workload | 0.48; dmnl | It is calculated by dividing the productivity by the normal workload. Accordingly, when productivity increases, the workload also increases |
| Adequate salary | 0; person/year | This means that authors' salaries should not be less than the country's average wage. Otherwise, they leave academia |
| Average author tenure | 30; year | It is the author's average academic activity duration, but it can be adjusted. This assumption is taken from local statistics |
| Average wage | 1.633 mln. KZT /person/ year | An average salary outside academia |


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**Table 2.** Variables in the subsystem (Papers published)

Source: Papers published.

| Variable | Initial values as of 2015, units | Description |
|---|---|---|
| Publication performance | 2,737; paper/year | The function MIN is used to select the minimum value of two inputs. The first variable input is based on the financial factor (potential funding for papers). The second input is based on the authors' factors (their number and productivity) |
| Papers published | 0 in 2015 | Total number of published papers from 2015 (initial value is set as 0) to 2030 |
| Productivity | 2.8; author/paper/year | Productivity is the rate at which authors can write, depending on the number of authors and the level of collaboration. The relevant studies recognized the positive impact of collaboration with foreign authors |
| h-index | 5; dmnl | An h-index is calculated as the number of published papers with a minimum citation number. This equation is an attempt to reflect this value based on observations of citations and publications of different authors |
| Academic age | 10; dmnl | The more professional a researcher is, the more productive he/she is |
| International collaboration | 1.1; dmnl | Many studies highlighted the benefits of international collaboration. There is evidence that international collaboration fosters productivity by 10.0%. It could be more or less, depending on sources or assumptions |
| Co-authorship | 4.21; person/paper | The previous studies found it is equal to 4.21 authors per paper |
| Local collaboration | 1.05; dmnl | It is assumed that local collaboration would impact productivity by 5.0% |
| Article writing time | 1, year | It is the sum of two variables: "article writing time" (0.96 years) and "peer review and revision" (1.02 years) |
| Research expenditures per paper | 25.2 mln. KZT/paper | This value was obtained as the average ratio of annual expenditures to the number of articles from 2015 to 2022. During 2015-2022, there were no significant fluctuations in this variable |
| Funding source | 69 bln. KZT/year | These are all research expenditures, which are summarized from the sums of expenditures of the state budget, research institutions, private business, and foreign investments |
| Research institutions and HEI investment | 25.3 bln. KZT/year | In 2015, there was KZT 25.3 bln allocated from research institutions for science, and each following year, it increased by 1.3% |
| Government investment | 40.7 bln. KZT/year | In 2015, there was KZT 40.7 bln funded from the state budget for research, and each following year, it increased by 8.7% |
| Foreign investment | 1.2 bln. KZT/year | In 2015, there were KZT 1.2 bln of foreign investments in research, and each following year, it increased by 11.2% |
| Private sector investment | 1.8 bln; KZT/year | In 2015, there was KZT 1.8 bln invested from private companies for research, and each following year, it increased significantly by 21.8% |

**Table 3.** Control limits for the MC simulation of the Authors and Papers published

Source: Input data in Vensim PLE Plus (Vensim, 2025).

| Variables | Distribution | Min | Max | Parameter | Distribution | Min | Max |
|---|---|---|---|---|---|---|---|
| **For the variable Authors** | | | | | | | |
| **–/+10.0% simulation** | | | | **–/+20.0% simulation** | | | |
| Average wage growth rate, % | Uniform | 0.126 | 0.154 | Average wage growth rate, % | Uniform | 0.112 | 0.164 |
| Ph.D. growth rate, % | Uniform | 0.09 | 0.11 | Ph.D. growth rate, % | Uniform | 0.08 | 0.12 |
| Average author tenure, year | Uniform | 27 | 33 | Average author tenure, year | Uniform | 24 | 36 |
| Normal workload, paper/person/year | Uniform | 0.9 | 1.1 | Normal workload, paper/person/year | Uniform | 0.8 | 1.2 |
| Job satisfaction, dmnl | Uniform | 0.9 | 1.1 | Job satisfaction, dmnl | Uniform | 0.8 | 1.2 |
| Productivity rate, paper/person/year | Uniform | 0.864 | 1.056 | Productivity rate, paper/person/year | Uniform | 0.768 | 1.152 |
| **For the variable Papers published** | | | | | | | |
| **–/+10.0% simulation** | | | | **–/+20.0% simulation** | | | |
| Research expenditure per paper, mln. KZT | Uniform | 22.68 | 27.72 | Research expenditure per paper, mln. KZT | Uniform | 20.16 | 30.25 |
| Government investment growth rate, mln. KZT | Uniform | 0.108 | 0.132 | Government investment growth rate, mln. KZT | Uniform | 0.096 | 0.144 |
| Private sector investment growth rate, mln. KZT | Uniform | 0.261 | 0.319 | Private sector investment growth rate, mln. KZT | Uniform | 0.232 | 0.348 |

sampling of random variables to produce results (Fishman, 2013). The MC approach is often used in modeling social, mathematical, and physical systems. Due to their reliance on iterative computation of random or pseudo-random numbers, these techniques are optimized for running on computing devices (Vensim, 2019). Given the changing nature of input variables, this simulation generates multiple forecasting outputs for a given performance factor. Forecasting of performance factors in any field is critical, and past studies emphasized the importance of examining the critical factors that impact it (De Marco et al., 2024; Ottaviani et al., 2023).

# 3. RESULTS

## 3.1. Sensitivity analysis results

This section presents the results of a sensitivity analysis conducted to determine the most significant factors affecting the publication performance output in the constructed SD model. The analysis helps to assess how changes in the input factors affect the key variables of the model, in particular, the number of active authors and the number of published scientific articles. The analysis was carried out using a range of ± 10% fluctuations for each factor with fixed values of the remaining variables, which corresponds to the generally accepted methodology for assessing the stability of models. These control limit values are used as an assumption following similar applications in previous studies (Samoilov et al., 2024a). Theoretically, the control limit of 10.0% is a standard statistical range for the sensitivity analysis (Vensim, 2019).

Figure 2 presents the sensitivity analysis results for each variable, which impacts the subsystem Authors. The subsystem Authors are highly influenced by the variables average wage growth rate, Ph.D. growth rate, average author tenure, normal workload, job satisfaction, and productivity rate. According to national statistics, the average annual wage in Kazakhstan in 2015 was 1.63 million KZT per person (NCSTE, 2020). Between 2015 and 2022, the wage growth rate averaged 14.0% per year, which projects a salary of approximately 11.63 million KZT by 2030 (NCSTE, 2023). If the wage growth rate were reduced by 10% to 12.6%, the projected average wage would decline to 9.67 million KZT. Therefore, work in the academy with the maintenance of all other factors will be more attractive, resulting in zero layoffs, since in the equation of this variable, there is a function [IF THEN ELSE (funding source/authors ≥ average wage, 0, authors-funding source/average wage)].

Source: Authors.

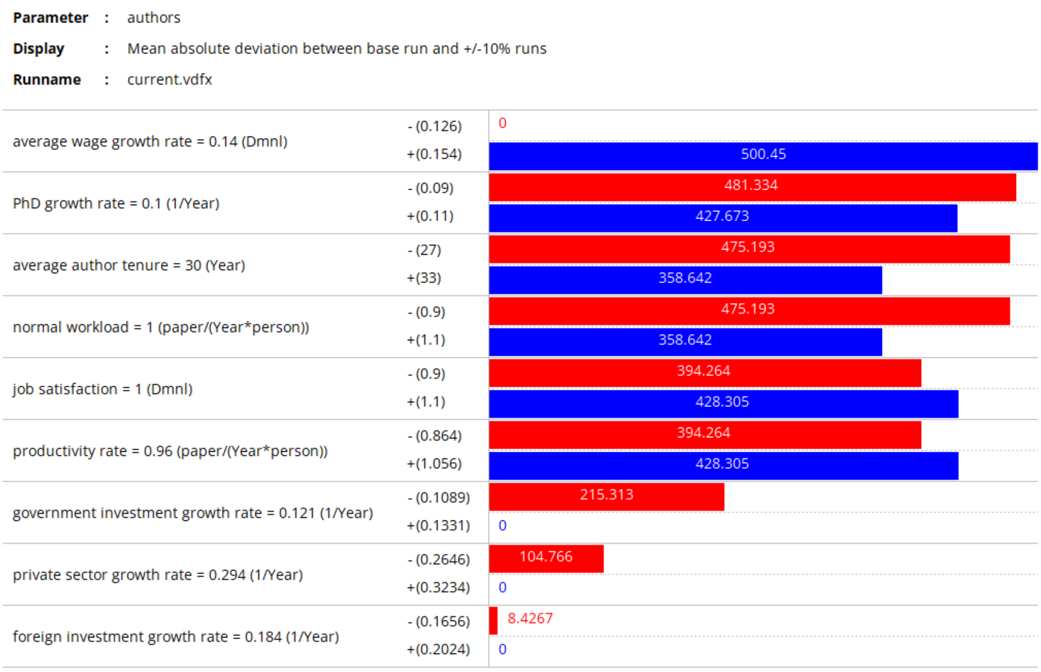


**Figure 2.** Sensitivity analysis of the subsystem (Authors)



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Source: Papers published.

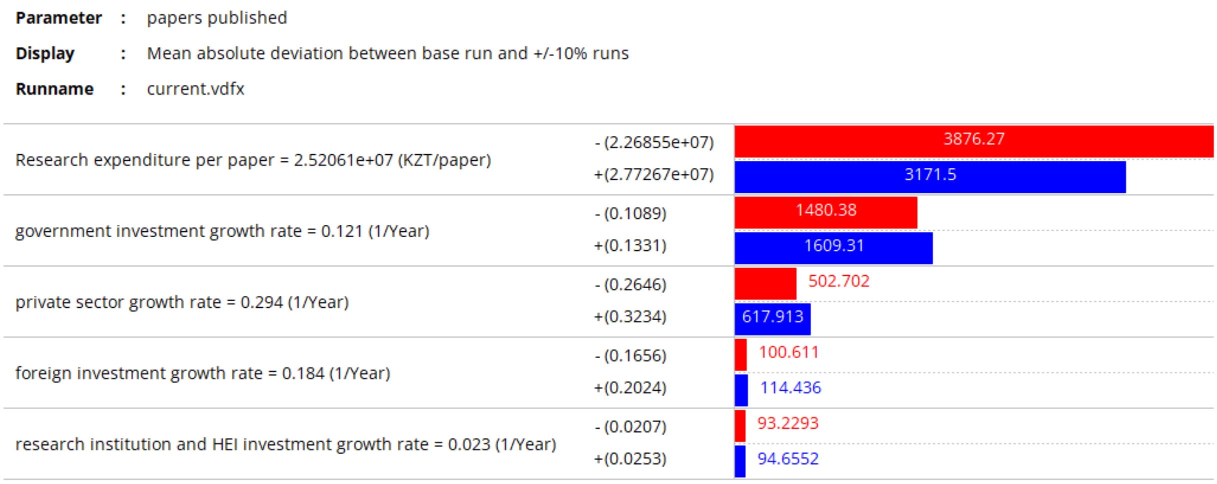


**Figure 3.** Sensitivity analysis of the subsystem (Papers published)

On the contrary, if the wage growth rate increases by 10% to 15.4%, the average wage would rise to 13.97 million KZT. In this scenario, academic positions would become less financially competitive than the private sector, leading to a yearly decrease of 500.45 authors.

The growth rate of the number of Ph.D. students plays an important role in the dynamics of the number of authors, so with a 10.0% drop from the growth rate of 0.1 to 0.09, there will be 481.33 fewer authors per year. Accordingly, changing the growth rate in Ph.D. students from a statistical average of 0.1 to a hypothetical 0.11 would increase the number of authors by an additional 427.67 per year.

While the growth rate of Ph.D. enrollment contributes to the increase in the stock of authors, other factors, such as average author tenure, normal workload, job satisfaction, and productivity rate, directly influence the rate at which authors exit academia. According to national statistics, the average academic tenure in Kazakhstan is estimated at 30 years (NCSTE, 2020, 2023). Reducing this tenure to 27 years would result in an annual decrease of approximately 475 authors, emphasizing the critical role of long-term career engagement in sustaining research capacity and the continuity of scientific knowledge production. Contrarily, if the working lifetime of the author is increased by 10.0%, i.e., the author will work in the profession for 33 years. Accordingly, the stock of authors will increase, in this case, by 358.64 authors per year.

Figure 3 presents the results for the variables that influence the subsystem Papers published. The three most influential variables affecting the number of published papers are research expenditure per paper, the growth rate of government investment, and the growth rate of private sector investment. Overall, from this analysis, we can see that the decrease in the research expenditure per paper by 10.0% (from 25.21 million KZT to 22.69 million KZT) will increase the number of published papers in Kazakhstan by an additional 3,876.82 papers published per year. In contrast, a 10.0% increase in this cost would reduce the publication output by about 3,171 papers per year. Government investment in research currently grows at an average annual rate of 12.1%. A 10.0% reduction in this growth rate would result in 1,480 fewer publications, while a 10.0% increase (to 13.31%) would produce an estimated additional 1,609 papers per year. Although private sector investment accounts for a smaller share of total research funding, it still has a measurable impact. A 10.0% decrease would reduce output by 503 publications, whereas a 10.0% increase would generate an additional 618 papers annually. These findings underscore the strong sensitivity of the publication performance to financial efficiency and the structure of national research investment.

## 3.2. MC simulation results

For the MC simulation, there were two different tests using the control limits for the most critical factors: setting the minimum and maximum limits as 10.0% and 20.0%, respectively (Table 3). Although a ±10%

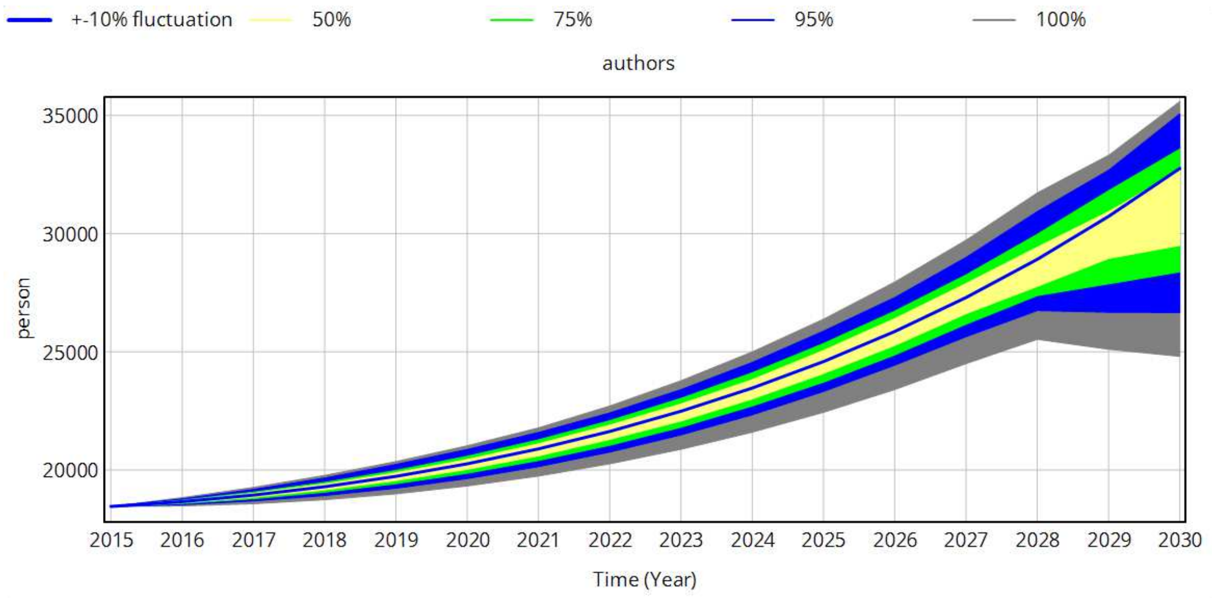


**Figure 4.** MC simulation results for the number of authors under ±10% variation

range is considered a conventional threshold for sensitivity and uncertainty analyses (Vensim, 2019), a ±20% range was also tested to reflect the broader volatility and policy risks typical of emerging economies like Kazakhstan (Amirbekova et al., 2022; Castelblanco et al., 2024b; Samoilov et al., 2024b). These simulations enhance the robustness of the model by estimating plausible future trajectories for both research capacity and scientific output under uncertain conditions.

The 6 most critical factors from the sensitivity analysis were selected for the subsystem Authors. The result of the simulation shows that for a +/–10% change in these variables (average wage growth rate, Ph.D. growth rate, average author tenure, normal workload, job satisfaction, and productivity rate) with a 95% probability, for the subsystem authors, the number of authors is in the range of 27,370 to 34,040.

The detailed output of this scenario is presented in Figure 4. Based on 200 iterations, the simulation reveals that with a 95% probability, the number of authors by 2030 will fall within the range of 27,370 to 34,040. Additionally, the 75% confidence interval indicates a more probable range between 29,126 and 33,620. These results highlight the moderate sensitivity of author retention and growth to small fluctuations in academic and economic conditions and demonstrate the effectiveness of the SD model in capturing realistic uncertainty in forecasting academic workforce dynamics.

In contrast, Figure 5 illustrates the simulation results for the ±20% variation scenario. Compared to the ±10% scenario, this wider fluctuation range introduces greater uncertainty into the forecast of the publication performance. With 95% probability, the number of authors in 2030 is estimated to lie between 23,560 and 36,917. The 75% confidence interval further narrows this projection to between 26,603 and 34,418. These results suggest that even moderate increases in input uncertainty across systemic drivers can considerably expand the forecast range, emphasizing the need to stabilize academic workforce conditions to support sustainable publication performance.

Table 4 represents the results of the MC analysis of the expected number of authors in the year 2030, given the possible variations in the values of all affecting variables within +/–10.0% and +/–20.0% according to the conducted 200 simulation runs. Both performed analyses show that the highest probable number of authors in 2030 will be between 28,800 and 32,200 (bold in the table). These forecast values are lower than those found by extrapolating the data for 2015-2022. The extrapolated data considers no uncertainty in the data and, therefore, produced more optimistic values for the number of authors, 32,763.6 in 2030. According to the number of simulations, this negative trend can be traced to other probable values.


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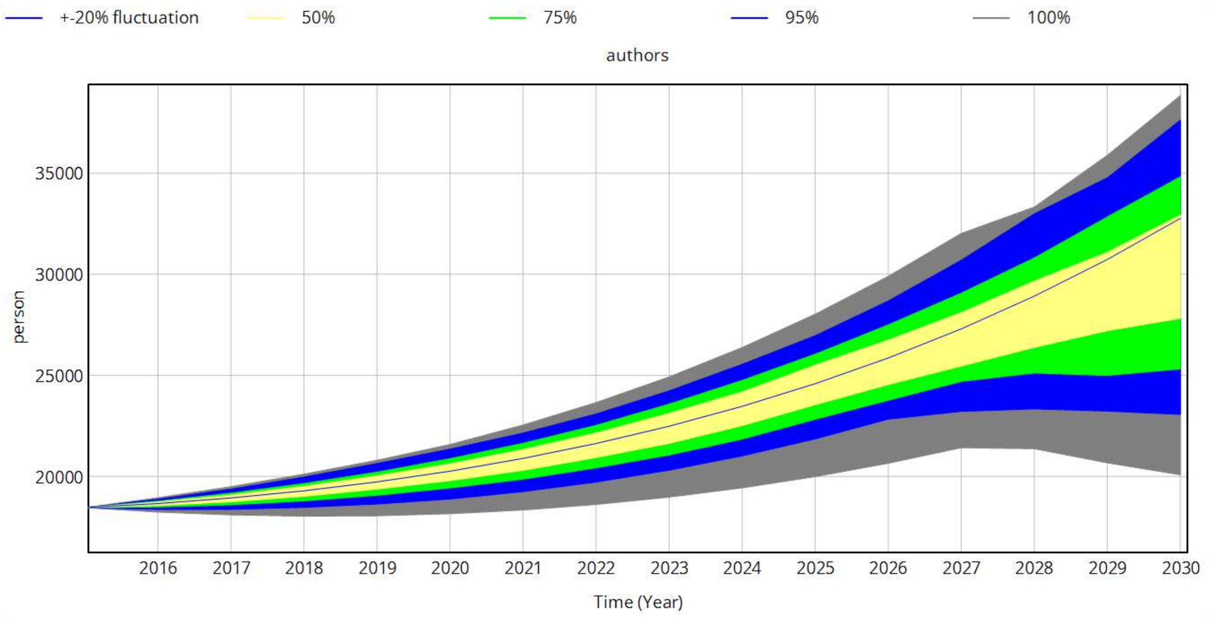


**Figure 5.** MC simulation results for the number of authors under ±20% variation

**Table 4.** MC forecast of the number of authors in 2030

Source: Output data in Vensim PLE Plus (Vensim, 2025).

| Forecasts of the number of authors in 2030 | Number of runs (the more runs, the more chance) | |
|---|---|---|
| | +/–10.0% value change | +/–20.0% value change |
| 18,600-20,300 | 0 | 0 |
| 20,300-22,000 | 0 | 5 |
| 22,000-23,700 | 1 | 10 |
| 23,700-25,400 | 2 | 16 |
| 25,400-27,100 | 20 | 34 |
| 27,100-28,800 | 35 | 28 |
| 28,800-30,500 | 56 | 35 |
| 30,500-32,200 | 61 | 35 |
| 32,200-33,900 | 13 | 20 |
| 33,900-35,600 | 0 | 7 |
| 35,600-37,300 | 0 | 3 |
| 37,300-39,000 | 0 | 0 |

Figure 6 presents the MC simulation results for the number of papers published in Kazakhstan under a ±10% variation. The simulation indicates that, with 95% probability, the number of publications in 2030 will range between 81,160 and 104,850. Within a 75% confidence interval, this range narrows to 84,626-100,498. These projections highlight the sensitivity of publication output to moderate financial fluctuations.

In contrast, Figure 7 illustrates the same simulation under a ±20% variation. The simulation was performed at 20% possible changes in variables. With a 95% probability, the number of publications will be in the range of 71,820 to 121,400. With a 75% probability, the number of publications will be in the range of 79,169 to 111,171. These findings underscore the increasing uncertainty in forecasting scientific output under volatile funding scenarios.

Based on 200 simulation runs, the MC test shows the probable number of articles published in the year 2030, given the variation in the values of the affecting variables within a +/–10.0% and +/–20.0% variations (Table 5).

**Table 5.** MC forecast of the Papers published in 2030

Source: Output data in Vensim PLE Plus (Vensim, 2025).

| Forecasts of the number of authors in 2030 | Number of runs (the more runs, the more chance) | |
|---|---|---|
| | +/–10% value change | +/–20% value change |
| 64,000-69,500 | 0 | 1 |
| 69,500-75,000 | 0 | 13 |
| 75,000-80,500 | 2 | 17 |
| 80,500-86,000 | 36 | 36 |
| **86,000-91,500** | **55** | **26** |
| **91,500-97,000** | **50** | **23** |
| **97,000-102,500** | **47** | **19** |
| 102,500-108,000 | 8 | 32 |
| 108,000-113,500 | 0 | 18 |
| 113,500-119,000 | 0 | 7 |
| 119,000-124,500 | 0 | 3 |
| 124,500-130,000 | 0 | 3 |

Source: Papers published under ±10% variation

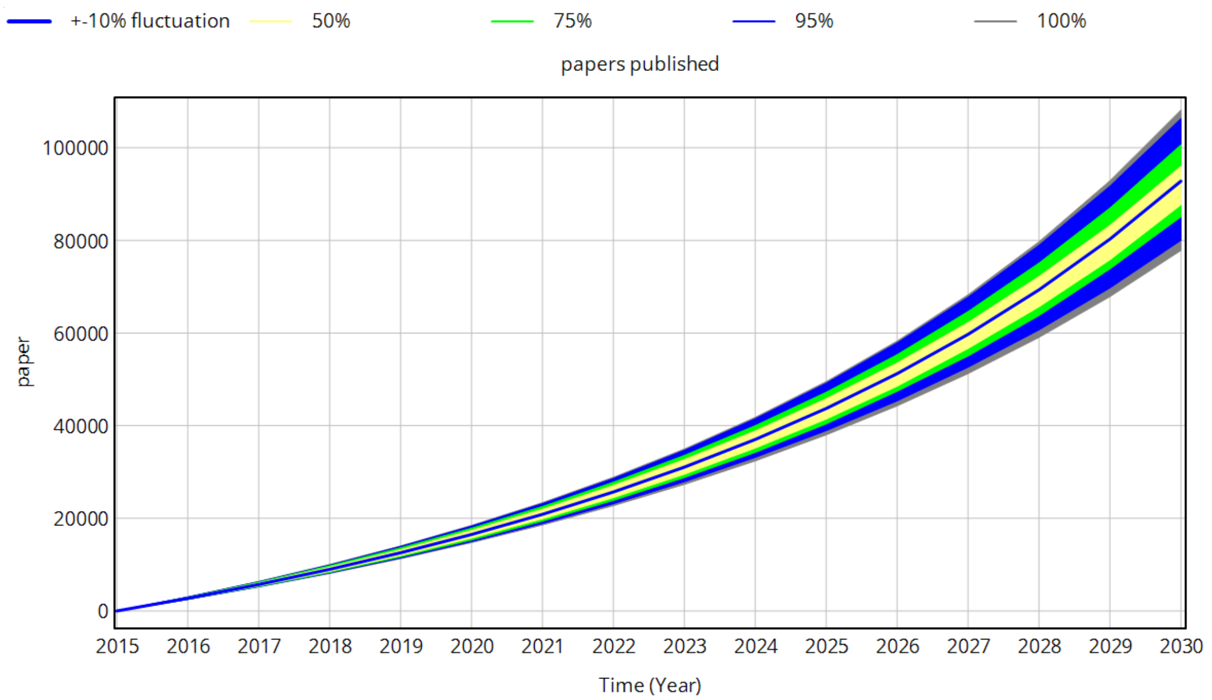


**Figure 6.** MC sensitivity graphs of the stock variable Papers published under ±10% variation

Source: Papers published under ±20% variation.

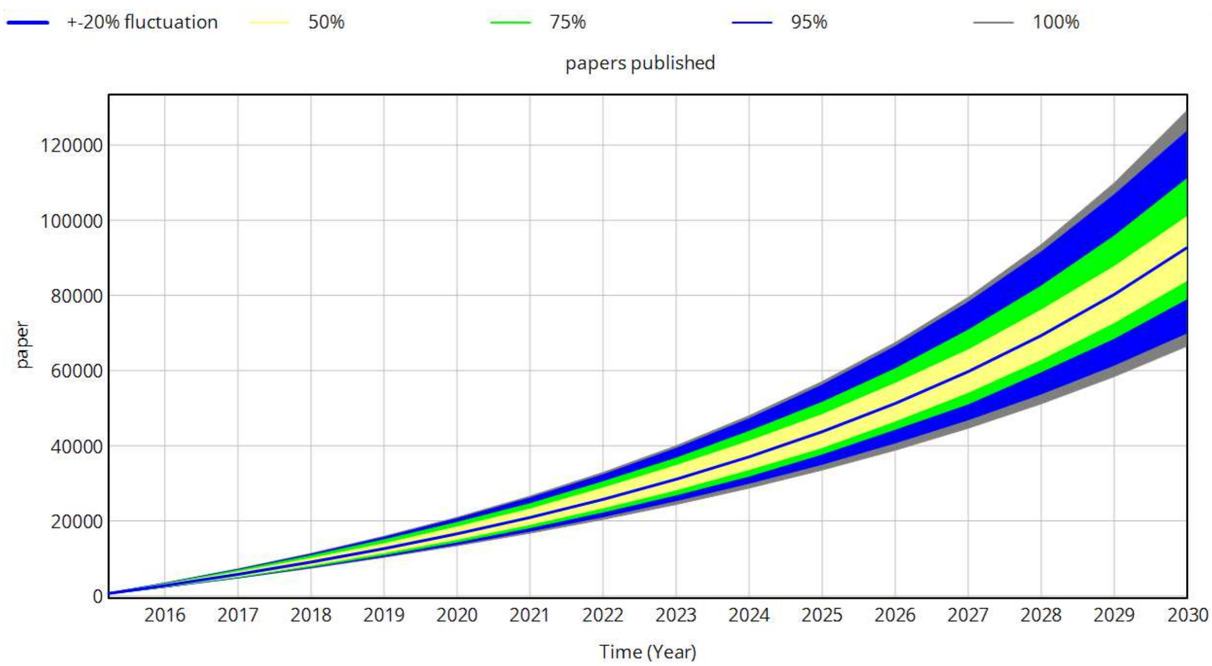


**Figure 7.** MC sensitivity graphs of the stock variable Papers published under ±20% variation

Taken together, the sensitivity and MC analyses highlight that small fluctuations in key inputs, such as tenure, funding, and productivity, can cause significant shifts in the long-term publication performance output. Therefore, with the change of values within +/–10.0%, between 86,000 and 102,500 papers will be published in 2030. If the values of the 3 factors deviate by +/–20.0%, the number of published papers is likely to be in the range of 80,500-86,000, but there is also a high


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probability that the number of papers published can reach the value of 102,500-108,000 in 2030. The results of the MC simulation analysis, which considers uncertainty, showed a slightly lower prediction in the number of articles that could be published in 2030. This is lower compared to the extrapolated data of 2015–2022, which are based on the predictions from past growth rates without considering uncertainty, 92,778.1 papers in 2030.

## 4. DISCUSSION

SD is a powerful simulation and forecasting approach that allows for modeling different scenarios of the publication performance in Kazakhstan. Considering the most critical factors in the science evaluation literature and practice, the proposed SD model simulated the impact of these factors on the publication performance output. In particular, the sensitivity analysis helped to identify the most significant factors that impact the publication performance. The MC simulation generated estimates for the country's range of publications. Considering uncertainties in these factors (Table A1, Appendix A) and the credibility of the real data on Kazakhstan (Tables 1 and 2), the model produced forecasts of the number of publishing authors and published papers through 2030.

The sensitivity analysis was conducted on the number of authors and published papers. Regarding the number of authors, the analysis revealed 6 variables as the most critical. These results are consistent with earlier empirical studies emphasizing the importance of salary conditions, workload, and job satisfaction in academic career retention (Wamala & Ssembatya, 2015; Negash et al., 2019). They are the average wage growth rate, Ph.D. growth rate, average author tenure, normal workload, job satisfaction, and productivity rate (Figure 2). It is interesting to note that the results from this study corroborate the findings of past studies, which stated that the most prevailing reasons for a researcher to continue an academic career after a Ph.D. are normal workload and job satisfaction in Kazakhstan (Narbaev & Amirbekova, 2021). Partly, the factors that determine salaries, Ph.D. numbers, and tenure conditions in institutions in the country were also critical and have been emphasized by the government (NCSTE, 2023). Regarding the level of the publication performance output, measured in the number of papers published, the three most impactful variables are the research expenditure per paper, government investment growth rate, and private sector investment growth rate (Figure 3). Since 2020, Kazakhstan has increased the level and sources of science funding, and the factors related to investments from the government and private sectors will remain critical. This aligns with the findings of Graf and Kalthaus (2018) and Uyar et al. (2022), who highlight that public and private R&D expenditures are strong predictors of national research output. As a suggestion, future studies can implement machine learning modeling (Narbaev et al., 2024), which can learn and improve the publication performance estimates using a larger dataset.

In the MC simulation analysis, a probable distribution of influencing factors was assigned, after which hundreds of plausible scenarios were generated within the assigned distributions. The results of the probability assessment were then analyzed. In the distribution of values, only those variables that had the greatest impact on the stock variables (from the sensitivity analysis above) were selected. First, the stock variable Authors was analyzed with changes in the parameters of all influencing variables in the range of –/+10.0% from the initial value. Then, this range was increased to –/+20.0%. Thus, the MC method showed that within the range of –/+10.0% with a probability of 95.0%, the number of authors will be from 27,370 to 34,040 in the year 2030, with a set range of values –/+20.0%, the number will be 23,560-36,917 authors. The MC analysis showed that the highest probability (with a value range of –/+10.0%) would be the number of authors between 28,800 and 32,200. Analyzing the stock variable Papers, the MC simulation showed that in the range of values variation –/+10.0% at 95.0% probability, the number of articles in 2030 will be from 81,626 to 104,850 pieces. With the range of values –/+20.0%, the number of articles will be 71,820-121,400. The MC analysis shows the highest probability that the number of articles will be between 86,000 and 102,500 in 2030.

# CONCLUSION

The current study aimed to examine the impact of various factors on the publication performance. To achieve this aim, it proposed a simulation model which quantitively measured the impact of key factors such as human capital, funding, career dynamics, and the institutional environment on the publication performance output in Kazakhstan. The six most critical factors that determine the number of publishing authors are the average wage growth rate, Ph.D. growth rate, average author tenure, normal workload, job satisfaction, and productivity rate. The three most critical factors that impact publication performance output were the research expenditure per paper, government investment growth rate, and private sector investment growth rate. Regarding the number of researchers, the analysis showed slightly lower estimates than the data from official statistics. The findings also suggested a low level of publication performance in the country by 2030. Kazakhstan was taken as a case country whose data is used to analyze the impact of such factors on the country's publication performance. It is noted that Kazakhstan, with its data, was taken as a case country. However, the proposed SD model can be scaled up and adapted to other countries using their data.

The findings of the current study can be helpful to the practice of scientific knowledge creation and science evaluation in both developed and developing countries. In particular, they can be considered in distributing funding, investing in research, fostering university-industry collaboration, and enhancing research productivity, which will inevitably strengthen national development and global competitiveness in the long run.

The following are the limitations of the current study. First, the model did not include all the factors mentioned in the literature, such as personal motivation, self-discipline, creativity, individualism, and other factors that may affect a researcher's performance. Second, due to the lack of data for some variables, reasonable assumptions were made to validate the model holistically (not focusing on the details) to test the publication environment in the country. Therefore, the proposed SD model is an example of a model that simulates the relationships between input factors and publication performance in the context of the country. The model is scalable to consider other factors or countries and is not constrained to the data or context of Kazakhstan. These limitations can be addressed in future studies.

# AUTHOR CONTRIBUTIONS

Conceptualization: Anel Kireyeva, Kuralay Nurgaliyeva, Yerzhan Mukashev.
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Funding acquisition: Anel Kireyeva, Kuralay Nurgaliyeva.
Investigation: Anel Kireyeva, Andrey Samoilov.
Methodology: Anel Kireyeva, Andrey Samoilov, Kuralay Nurgaliyeva.
Project administration: Kuralay Nurgaliyeva, Yerzhan Mukashev.
Resources: Yerzhan Mukashev.
Software: Anel Kireyeva, Andrey Samoilov.
Supervision: Anel Kireyeva, Yerzhan Mukashev.
Validation: Andrey Samoilov.
Visualization: Andrey Samoilov.
Writing – original draft: Andrey Samoilov.
Writing – review & editing: Yerzhan Mukashev.


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# APPENDIX A

**Table A1.** Critical factors used for SD modeling

| Critical factor | Description | Sources |
|---|---|---|
| **Factor group: Authors related** | | |
| Job satisfaction | Researchers can experience job dissatisfaction from the work environment and policies | Abramo et al. (2009) |
| Workload | The workload of an author depends on both extensive research and/or teaching activities | Wamala and Ssembatya (2015) |
| Adequate salary | The satisfaction of academics with salary contributes to their productivity. The dissatisfaction can lead to leaving academia | Negash et al. (2019), Wamala and Ssembatya (2015) |
| Ph.D. number | It is limited by state funding and higher education costs. The more Ph.D.s engage in research, the more publications will be produced | Menon et al. (2018) |
| **Factor group: Productivity related** | | |
| Local collaboration | Collaboration among different institutions and departments/schools. It enables the sharing of scientific knowledge, networking, and providing mentorship, especially for young researchers | Jamali et al. (2024), Abramo et al. (2009) |
| International collaboration | Collaboration of authors from different countries working on similar research objectives | Jamali et al. (2024), Vuong et al. (2019), Abramo et al. (2009) |
| Co-authorship | Two or more authors work on the same article | Wamala and Ssembatya (2015), Chatterjee et al. (2020), Panikarova et al. (2017) |
| Academic age | Career experience, age of the author's professional academic activity (often started after obtaining a Ph.D.) | Rørstad and Aksnes (2015), Wamala and Ssembatya (2015) |
| h-index | A metric for productivity, measured by quantity (publication number) and quality (citation number) | Pastor et al. (2015) |
| Article writing time | It reflects writing and publication time, including all procedures (submitting, acceptance, reviewing) | Chatterjee et al. (2020), Panikarova et al. (2017) |
| **Factor group: Funding source related** | | |
| Private sector investment | Firms collaborate with institutions, investing in R&D to develop new ideas, gain expertise, and acquire innovative technologies | Karlsson et al. (2004) |
| Research institutions and HEI investment | Budgets to public and non-public universities for research through different programs, grants, subsidies | Graf and Kalthaus (2018), Uyar et al. (2022) |
| Government investment | The expenditures on research represented as a percentage of the gross domestic product | Pajo et al. (2020) |
| Foreign investments | Funding received from international or foreign organizations | Zhang (2017) |