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Development of a Private Space Sector in the U.S. and Russia

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Abstract

This work analyzes progress and challenges in the development of commercial space economies in the United States and Russia. Space development progress is characterized through examination of three production indicators for the space economies in each country and econometric analysis of the financial data for three new American private space companies. We also provide case studies of major challenges faced by three new private space companies and conjecture about the future of the private space industry through analysis of space education projects in each country. As leaders of space technological development and exploration, the U.S. and Russia are major stakeholders in the current and future global space economy. We find access to capital is a primary barrier to entrepreneurship. The results will help future founders more effectively navigate the complex financial, regulatory, and technological landscape of the space industry.

Keywords: Commercial space, entrepreneurship, venture capital, econometric analysis, launch frequency, space development

1. Introduction

The global space economy has long been dominated by government agencies and their major contractors in efforts to pursue national objectives, such as human exploration, defense, and communications. The U.S. and Russia have historically been two of the biggest players in space with programs dating back to the 1950s. With new national priorities of returning to the moon and service of the broader public for information technology and telecommunications, both the United States and Russia look to establish viable commercial space economies to claim a piece of a market worth nearly $400 billion, as shown in Figure 1. The majority of this space market is currently captured by large government contractors, but new private space companies are quickly popping up to take advantage of the burgeoning private-sector space investment available for rapid growth.

This paper will focus on the development of the private space economy specifically within the U.S. and Russia. These two countries have been selected due to their long history of participation in the space sector. The development of private space sectors in each country is assessed from three perspectives: space economy, space policy, and space education. An introduction with background information in each of the three areas of interest will first be presented, followed by a summary of findings and conclusions as to what may be needed for the private space economy to further grow.

From the economic perspective, private space companies repeatedly demonstrate an ability to cut costs and innovate at a faster rate than government organizations like the National Aeronautics and Space Administration (NASA) and the Roscosmos State Corporation for Space Activities (Roscosmos). Privately-developed reusable rockets, for example, lower the cost of launch to low-Earth orbit by over ninety percent and small satellite constellations offer inexpensive global coverage for communications and remote sensing applications. These efforts create sustainable business opportunities in space beyond defense [1, 2].

Key areas for promoting sustainable commercial space economies include reducing the financial risk of expensive space endeavors through public-private partnerships, developing new regulations that balance development with preservation of space, and improving access to space for educational and academic institutions to promote the vitality and training of a new space workforce.

Space exploration is still an expensive proposition, but public-private cost sharing offers financial risk reduction benefits to both sectors. Governmental product development and launch contracts awarded to private corporations foster competition, promoting innovation and lowering the

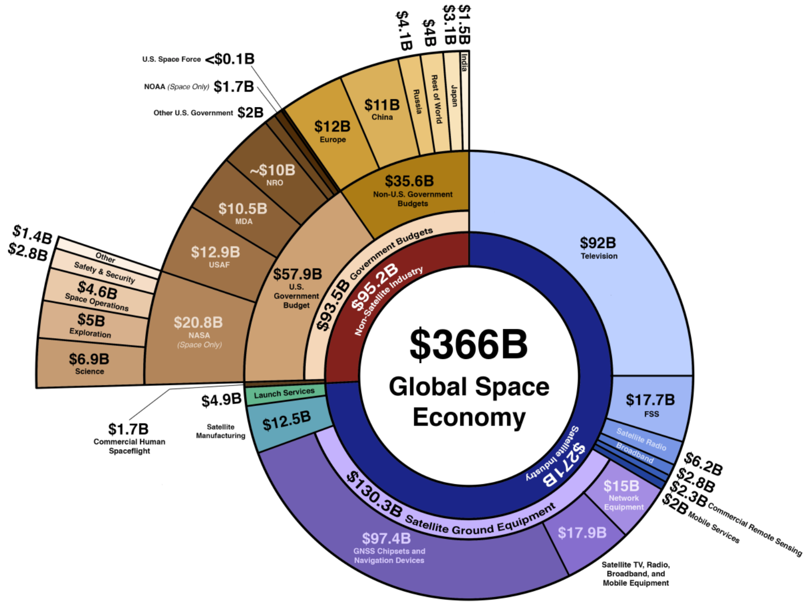


Figure 1: The global space industry is currently valued at nearly $400 billion. (reproduced from ”The 2019 Global Space Economy at a Glance.” [3])

cost per production unit. Additionally, government contracts incentivize private companies to align their product or mission with national technology needs [4]. Soliciting governments-as-customers is one way new private space companies can obtain the large amount of capital needed to develop a new technology, operate, and acquire customers needed for sustainability. The rise of an internationally competitive industry for space activities is a logical, probable, and beneficial outcome in an increasingly globalized world [5]. This premise is further supported by work correlating public opinion with the congressional NASA budget which acknowledged the support of the American public for the commercialization of space [6].

One of the most prominent examples that highlights the benefits of the aforementioned public-private partnership is the International Space Station (ISS). The space agencies of the U.S., European Union, Canada, and Japan all collaborated on the initial multilateral agreement that enabled large-scale cost-sharing for the program. The success of the ISS program was marked not only by the dedicated international partnerships, but also by increased support from the U.S. Congress [7]. Russia also eventually joined the ISS program, bringing expertise in human space exploration and space station development. The cooperation of the U.S. and Russia on the development and operation of the ISS was critical to opening doors to productive conversations in national security and foreign policy [8]. Private corporations such as United Launch Alliance and Space Exploration Technologies are now becoming increasingly involved with the ISS program by providing resupply services. These public-private partnerships for the ISS are an example of how government programs can provide a stable source of demand and revenue to enable the maturity of space technologies developed by private companies.

From the perspective of space education, the U.S. and Russian private and public space sectors have significant influence on the educational environment in both countries. Promotion of Science, Technology, Engineering and Mathematics (STEM) education and workforce training through space-themed science programming is an expensive endeavor for each country that does not reap immediate rewards but is necessary for national competitiveness. The ISS provides opportunities for students and faculty around the world to interact with the space environment. Examples of popular ISS-enabled STEM engagement opportunities include using the Sally Ride EarthKAM to collect images of Earth from the station, using the Amateur Radio Aboard the ISS (ARISS) to converse with astronauts about life in space, and performing robotics and control experiments with the Synchronized Position, Hold, Engage, Reorient Experimental Satellites (SPHERES) [9, 10, 11]. Additionally, the ISS enables deployment of academic CubeSats which are increasingly used as a tool for teaching space system design, space system testing, and space mission design concepts [12]. Facilitating hands-on, team-based projects that encourage active learning result in greater retention of students in STEM fields and demonstrate the commitment of ISS partners to encourage the participation of youth in space endeavors.

Turning to space policy, understanding the structure and motivations of NASA and Roscosmos motivates insights into the evolution of the private space companies they support. In the U.S., NASA's longstanding national identity as the gatekeeper of the civilian space industry is shifting to enable private companies to own more aspects of space operations. NASA is becoming more decentralized in favor of public-private partnerships which help to grow private stakeholders and space competition, effectively lowering costs and accelerating innovation [13]. This support has multiplied investment in space since these activities reassure investors that successful companies will be able to keep profits and grow [14]. In Russia, the space industry is still primarily centralized within Roscosmos, which has faced difficulty in cultivating new space companies whose product offerings may pose competition to those of the state corporation [15]. The development of the private space sector is a prime concern for the Russian government as it seeks to strengthen its technological independence and stature as a primary stakeholder in space activities [16]. While the influx of venture capital into American space companies has enabled their increasing independence from NASA, this form of capital is less available for Russian space companies. According to Space Capital, in 2020, nearly fifty percent of space industry venture funding went to U.S.-based companies while less than one percent was invested in Russia-based companies [17]. Russian space companies currently rely on friends and family rounds as well as grants from organizations like the Skolkovo Foundation Space Cluster and Roscosmos to get started. Similar access to the large amount of capital required for new space companies to rapidly grow and acquire customers, however, does not yet fully exist for Russian space entrepreneurs.

2. Methods

This work analyzes progress and challenges in the development of commercial space economies in the U.S. and Russia through analysis of launch activity data, financial data for three private space companies, regulatory and environmental challenges, and STEM engagement opportunities. In analyzing launch activity data and private company financial data, this study aims to identify space economy developmental trends in both countries. Studying the challenges space companies face also improves our understanding of opportunities for innovation in how national space organizations interact with new companies. As for ealuating STEM engagement opportunities, this provides insight as to how each country's national competitiveness in space is progressing into the future.

For the analysis of launch activity data, a dataset was created comprising U.S. and Russian launch activity by commodity from a variety of sources [18]. The dataset includes time series data for rockets launched, small satellites launched, and humans launched. Demand for these commodities has created opportunities for innovation and entrepreneurship over the past decade with growing interest in the establishment of space transportation, telecommunications, remote sensing, and tourism infrastructures.

As for the analysis of private company financial data, a dataset was created from a variety of sources for three private space companies in the U.S. to perform econometric analysis [19, 20]. Econometric analysis is a statistical approach used to quantify between-variables effects in complex, multivariate systems over a period of time. This work used the Johansen Vector Error-Correction Mechanism (VECM) approach to detect correlation between valuation, revenue, intellectual property[1], and company size[2] [21, 22, 23]. These variables organized by fiscal quarters which are typically used by companies for financial reporting. The VECM approach was selected for its robustness as a time-series analysis technique. The model allows for the identification of multiple co-integrating vectors that predict dependent variables as functions of multiple independent variables changing over time. The approach was implemented using Stata/BE 17.0 data analysis software. The independent variables, comprising revenue, intellectual property, and company size data, were pre-processed into levels through a natural logarithm transform. The parameters of lag length and number of co-integrating equations were selected through performing stability tests for different values of these parameters. The results presented in this paper used a single co-integrating equation and a lag length of two, which means that the variable values of the previous two time steps are used as well as with those of the current time step to create the model.

[1] Intellectual property was considered as the number of patents held at any given time.

[2] Company size was considered as the number of employees at any given time.

3. Results

3.1 Launch Activity by Commodity

The quarterly launch frequency for rockets, small- to mid-sized privately-developed satellites (smallsats)[3], and people launched into space from the U.S. and Russia from 2011 to 2021 is shown in Figure 2. The rocket, smallsat, and human launch commodities were examined to understand the relative participation of each country over time. Both countries launched a comparable number of orbital rockets throughout the decade. The number of cumulative rocket launches is consistent in the beginning of the decade between each country, but launch frequency is currently trending in opposite directions. Based on the rocket launch frequencies shown in Figure 2, Russia currently has a decreasing trend in rocket launch frequency whereas the U.S. has an increasing trend. Small satellite launch frequency data shows a growth phase for the small satellite economy in the U.S., which is led by the rapid expansions of the satellite mega-constellations curated by Space Exploration Technologies, Planet Labs, Spire Global, and Swarm Technologies. The U.S. launched over 2,600 small satellites during this time period compared to 27 launched from Russia. People launched into space, on the other hand, shows the U.S. halt in astronaut launches over the past ten years after the retirement of the space shuttle in 2011. Russia, however, maintained a steady human launch cadence. The U.S. launched 26 people to space during this period whereas Russia launched 106 people to space.

3.2 Econometric Analysis of Private Corporate Data

The econometric analysis applied the Johansen VECM approach to the companies' quarterly time-series financial data as described in the **Methods** section. Three private space companies were chosen for the analysis based on their size, ease of access to data, and length of operation. The three companies studied in this paper are Relativity Space, Planet Labs, and Space Exploration Technologies. The companies can be categorized as mid to large, with current approximate number of employees being 357, 624, and 9,500. The VECM analysis was used to predict company valuation as a function of revenue, human capital (number of employees), and institutional capital (intellectual property as represented by the number of patents). This specification was used for all three companies, with the exception that Relativity Space did not incorporate patents as an independent variable since it had no patent information until early 2021. This means that the variable *Patents* does not have enough information to be meaningful in the VECM analysis for Relativity Space.

The results of the VECM output for each of the three companies are reproduced from Stata in Tables 1–3. Each table caption also includes the corresponding χ^2 value, where larger χ^2 values loosely correspond to a better model. Additionally, the Johansen VECM stability plots are included in Figure 3, and show the eigenvalues of the companion matrix obtained in the modeling. All eigenvalues lie within the unit circle for each of the stability plots, indicating the models presented in Tables 1–3 are properly specified. The resulting equations 1–3 show the relationship between the log levels of the dependent and independent variables from each of the VECM calculations corresponding to Tables 1–3, respectively. It is important to note that the variable coefficients shown in the tables for the log levels of *Annual Revenue, Employees, Patents,* as well as the constant, will change sign when moved to the right hand side of the equation.

Equation 1 suggests that the valuation of Relativity Space is positively correlated with annual revenue while negatively correlated with the number of employees. Again, the patents were not included in the VECM specification for Relativity Space since there was no patents on file until early 2021.

Equation 2 indicates a similar result as that for Relativity Space, with the valuation of Planet labs being positively correlated with the company's revenue while negatively correlated with the number of employees in the company. For Planet Labs, the valuation is shown be positively correlated with the number of patents.

Equation 3 is in juxtaposition to the results for both Relativity Space and Planet Labs in that the correlation between the valuation of Space Exploration Technologies and its annual revenue and number of employees is reversed. This could be due to the way the company was initially founded and supported, and should be further studied. The correlation with patents, however, is consistent with the findings for Planet Labs.

$$\ln \text{Valuation} = 55.75 + 18.72 \times \ln \text{Annual Revenue} - 20.33 \times \ln \text{Employees} \tag{1}$$

$$\ln \text{Valuation} = 11.62 + 0.87 \times \ln \text{Annual Revenue} - 1.23 \times \ln \text{Employees} + 0.28 \times \ln \text{Patents} \tag{2}$$

$$\ln \text{Valuation} = -43.41 - 9.21 \times \ln \text{Annual Revenue} + 11.90 \times \ln \text{Employees} + 0.08 \times \ln \text{Patents} \tag{3}$$

[3]The satellites of interest are those which use commercial off-the-shelf components rather than space-rated components to drive cost saving. Satellites in the mass regime of 250 kg or less were included.

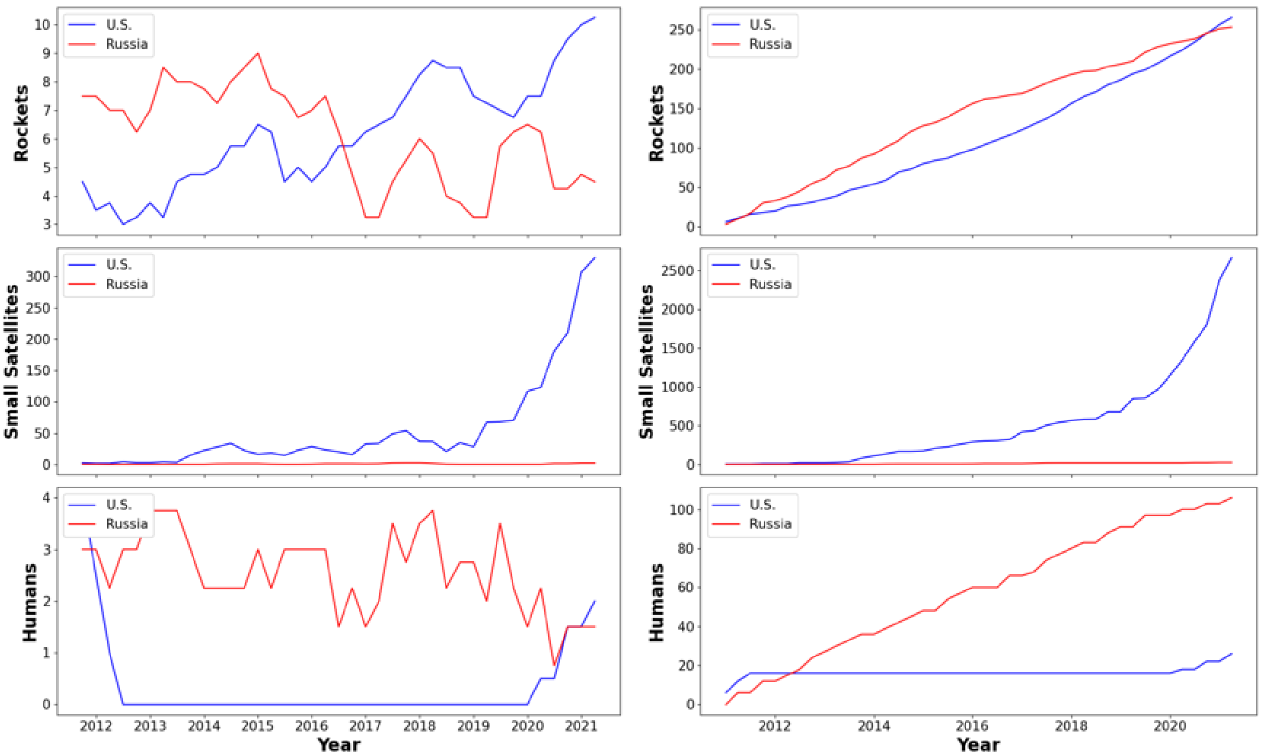


Figure 2: The launch activity by commodity data reflects the current health of space economic good production. Left: Launch frequency moving average with a window size of one year Right: Launch frequency cumulative

Table 1: Johansen VECM Results for Relativity Space, $\chi^2 = 51.3$

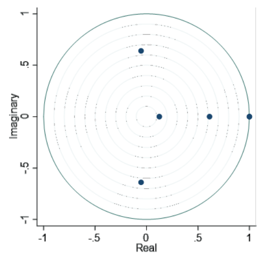
Variable	Coefficient	Standard Error	z-Score	P $>\|z\|$	95% Confidence Interval	
ln Valuation ($M USD)	1	-	-	-	-	-
ln Annual Revenue ($M USD)	-18.72027	2.703769	-6.92	0.000	-24.01956	-13.42098
ln Employees	20.32726	3.20515	6.34	0.000	14.04528	26.60924
Constant	-55.75411					

Table 2: Johansen VECM Results for Planet Labs, $\chi^2 = 622.6$

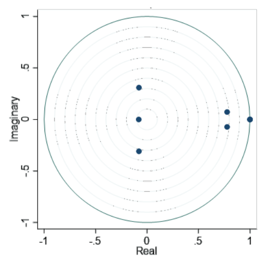
Variable	Coefficient	Standard Error	z-Score	P $>\|z\|$	95% Confidence Interval	
ln Valuation ($M USD)	1	-	-	-	-	-
ln Annual Revenue ($M USD)	-0.873278	0.123918	-7.05	0.000	-1.116153	-0.630402
ln Employees	1.232149	0.156807	7.86	0.000	0.924813	1.539485
ln Patents	-0.281890	0.012735	-22.13	0.000	-0.306851	-0.256930
Constant	-11.62389					

Table 3: Johansen VECM Results for Space Exploration Technologies, $\chi^2 = 86.3$

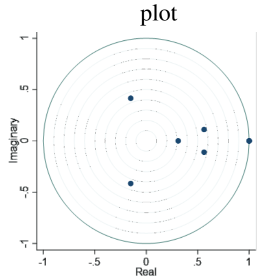
Variable	Coefficient	Standard Error	z-Score	$P > \mid z \mid$	95% Confidence Interval	
$\ln$ Valuation ($M USD)	1	-	-	-	-	-
$\ln$ Annual Revenue ($M USD)	9.209365	1.509213	6.10	0.000	6.251361	12.16737
$\ln$ Employees	-11.89959	1.726609	-6.89	0.000	-15.28368	-8.515501
$\ln$ Patents	-0.082954	0.0883652	-0.94	0.348	-0.2561467	0.0902386
Constant	43.41465					



(a) Relativity Space stability plot



(b) Planet Labs stability plot



(c) Space Exploration Technologies stability plot

Figure 3: Johansen VECM Stability Plots

3.3 Case Study

In reviewing business challenges new space companies face, the issue of accessing capital is a theme in both countries. Access to capital is one of the most important factors new companies need to demonstrate new technology, enter market, and acquire customers. Access to private capital exists in the U.S. in the form of venture capital, private equity, debt financing, grant funding, angel investment, friends and family investment, and public offering; venture capital investment was the primary form of fundraising for new space companies in the U.S. in 2019 [3]. Russian space entrepreneurs have less access to capital than American space entrepreneurs: in Russia, investments typically come from grant funding from organizations like the Skolkovo Foundation and Roscosmos. Russian founders have difficulty accessing foreign venture capital due to sanctions and restrictions on foreign investment in the space industry. In both countries, it is difficult for founders to raise money due to the inherent risk of participating in the space industry. Global rocket launch failure rates are still in the range of 1 in 10 to 1 in 25, and 40% of cubesats fail to reach their intended orbit and achieve mission objectives, as was the case for Dauria Aerospace's satellites in 2017 and Audacy's satellite in 2018 [24] [25]. Finally, regulations can inhibit corporate vitality. As an example, in 2018 the FCC fined fledgling startup Swarm Technologies nearly $1 million for its unauthorized launch of SpaceBees. Importantly, competition is not frequently cited as a major challenge new private space companies face. The lack of competition in the space industry relative to other industries suggests the industry is primed for a surge in new entrants, so long as financial and regulatory circumstances offer favorable access.

3.4 STEM Engagement

Education and opportunities to engage directly with space science and technology improve the quality of human capital available to the space industry. One way to characterize this engagement quantitatively is the launch of satellites by academic institutions for educational purposes. Figure 4 shows the moving average of the number of small satellites launched by educational and academic institutions specifically in the U.S. and Russia over the past decade, with data taken from the satellite launch frequency dataset.

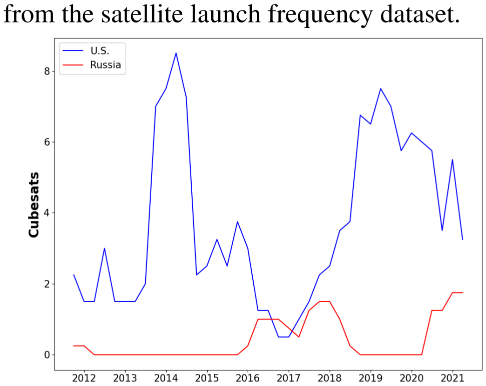


Figure 4: Moving average of the cubesat launch frequency

While this is only one way of characterizing student STEM engagement, these data suggest the U.S. may offer more opportunities for student involvement in hands-on space-related projects than Russia.

4. Broader Implications and Significance

The private space sector is a developing part of the space industry. This work studies the primary aspects of the development of the private space sectors in the U.S. and Russia. The research will provide useful insights into the development of the private space economy, strategies for successful corporate development, and the development of talent pipelines in both countries. The findings can be used by policymakers, private space company executives, government officials, and educators to improve the future global space sector.

5. Conclusions

This work presented an analysis on the development of the private space sectors within both the U.S. and Russia. The development of the sector was viewed through the perspectives of space economy, space policy, and space education and a summary of the evolution of the space industries in both countries was provided. The methods were then discussed that were used to analyze the current status of the private space sectors. Quarterly launch data was analyzed and presented for both countries to identify recent trends in the launch markets of the U.S. and Russia. Results of a time-series econometric analysis were presented for three private space companies to predict company valuation as a function of revenue, human capital in the form of number of employees, and institutional capital in the form of patent intellectual property. Lastly, a summary was presented from lessons learned through discussions with experts and investors from both the U.S. and Russia, as well as recent developments in the space economies.

This work concludes:

1. Access to capital is a primary driver for to entrepreneurship in both the U.S. and Russia.
2. The rapid growth in the U.S. small satellite launch frequency is a result of recently increasing venture capital investment in space companies.
3. The Johansen VECM modeling approach was used to predict company valuation as a function of revenue, human capital, and institutional capital.
4. Two early-stage private space companies showed that valuation is positively correlated with revenue, but negatively correlated with number of employees.
5. The global space industry is primed for new entrants with little extant competition.
6. Startup ecosystems such as the Skolkovo Innovation Center are beginning to provide increased access to capital in Russia for new space companies.

6. Future Work

This work presented quantitative methods for identifying trends in the development of the commercial space economies in the United States and Russia. Future work will add additional companies to the econometric analysis section and a panel regression analysis will be used in an attempt to characterize the relationships for the broader private space sector in general. Additional efforts will also be made to create a similar yet parallel dataset for several early-stage Russian private space companies. To offer a plurality of evidence supporting conclusions about industry barriers that space founders face in starting and growing new enterprises, future work will include a qualitative study of the perspectives of space venture founders and investors to gain insight into external factors influencing company growth. Additionally, future work will survey engineering students involved with space-related research and projects to further understand opportunities for space-related STEM engagement and project-based learning to gain an understanding of the opportunities available to the space entrepreneurs and workforce of the future.

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