The influence of scientific research output of academics on economic growth in South Africa: An autoregressive distributed lag (ARDL) application

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Abstract

An increasing number of researchers have recently shown interest in the relationship between economic growth of a country and its research output, measured in scientometric indicators. The answer is not only of theoretical interest but it can also influence the specific policies aimed at the improvement of a country's research performance. Our paper focuses on this relationship. We argue that research output is a manifestation of the improvement of human capital in the economy. We examine this relationship specifically in South Africa for the period 1980–2008.

Using the autoregressive distributed lag (ARDL) method, we investigate the relationship between GDP and the comparative research performance of the country in relation to the rest of the world (the share of South African papers compared to the rest of the world). The relationship is confirmed for individual fields of science (biology and biochemistry, chemistry, material sciences, physics, psychiatry and psychology).

The results of this study indicate that in South Africa for the period 1980–2008 the comparative performance of the research output can be considered as a factor affecting the economic growth of the country. Similarly, the results confirm the results of Vinkler (2008) and Lee et al. (2011). In contrast, economic growth did not influence the research output of the country for the same period. Policy implications are also discussed.

Keywords: research output; publications; economic growth; ARDL; South Africa

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1. Introduction

Knowledge accumulation is considered one of the key factors affecting the productive capacity of a country and, hence, its capacity for international competitiveness. Romer (1986), for example, supported that a given firm is more productive the higher the average knowledge stock of other firms is. This was done by modelling endogenous growth due to knowledge externalities. Romer (1986), however, did not specify whether this knowledge should be considered as disembodied (knowledge in books, etc.) or embodied (physical and/or human capital).

The importance of knowledge accumulated in human capital was also extensively stressed in Lucas (1988). Tamura (1991) examined a human capital externality based on the idea that individuals learn from the knowledge of others. For the South African case, Fedderke (2005) found that the quality of human capital is the most important aspect for economic growth, rather than the quantity thereof. He reports empirical evidence in favour of a positive impact on economic growth by innovative activity as it is defined by Schumpeter (2000). To clarify the ways in which knowledge can be incorporated into the production of the economy, Schumpeter (2000) distinguished between *invention* which he defined as "... the discovery of new technical knowledge and its practical application to the industry", and *innovation* which he defined as "... the introduction of new technical methods, products, sources of supply and forms of industrial organisation".

The quality of human capital can be improved by a number of activities such as higher education, training on specific skills and life-education. More specifically, for instance, human capital can be enhanced through involvement in research activities, such as reading literature, learning new methods and producing research output. The improvement of the quality of human capital through production of research output can lead to an improvement of economic production through a channel as presented in Figure 1.

Fig. 1 Mechanism of the effect of the quality of academic human capital on economic growth

The suggestion is that variation in the size of the research output of a country is to a certain extent the result of variations in the number of academics, researchers and post graduate students –

the producers of research. Even though research productivity changes may affect the research output over time these are expected to be relatively small. The variation in size of research community further permeates in other facets of economic life (e.g. productivity, innovation and similar) resulting in changes in economic growth.

The academics' research output also represents the accumulated new knowledge produced in the country. In the literature, different indicators have been used to proxy accumulated knowledge in a country. Examples include Research and Development (R&D) expenditures (Fedderke & Schirmer, 2006); knowledge measured as the research output of a country (De Moya-Anegon & Herrero-Solana, 1999; King, 2004; Vinkler, 2008; Lee et al., 2011). The suggestion is that research output reflects both quality of human capital and accumulated new knowledge.

Lee et al. (2011) point out that there is no consensus achieved in this literature as to whether research output as a measurement of accumulated knowledge affects economic growth or vice versa. Nevertheless, all the studies regarding this subject fully agree that there is certainly some kind of association (Price, 1978; Kealey, 1996; King, 2004; Vinkler, 2008; Lee et al., 2011) but the direction and magnitude thereof varies depending on the specific case and the time period examined.

The purpose of this paper is to partially fill the debate by examining the relationship between research output measured in scientometric terms and economic growth in South Africa for the period 1980–2008. Here, the research output is assumed to influence economic growth through the improvement of academic human capital which is the main creator of knowledge in a country.

The main contributions of this study are as follows:

i) Firstly, special focus is given to academics' research output which is measured primarily in published articles;

ii) Secondly, research output is measured by the comparative research performance of the country in relation to the rest of the world in terms of number of publications (scientometric indicator).

iii) Finally, contrary to Fedderke and Schirmer (2006) who looked only at the manufacturing sector, we analyse the effects on the overall economy by the total local research output as well as various fields of study in the country.

The rest of this paper is organised as follows: A brief literature review focusing primarily on recent studies which have used scientometric indicators as proxies of research output as well as a discussion on the ways of measuring research output are presented in Section 2. Section 3 outlines the empirical econometric methodology employed in this study. Section 4 presents the data used in the analysis and the empirical results are presented in Section 5. Section 6 summarises the main findings of the paper and discusses policy implications.

2. Literature review

The interest regarding the relationship between knowledge and economic growth is certainly neither recent nor innovative (Romer, 1986; Lucas, 1988; Tamura, 1991; Schumpeter, 2000). Nevertheless, the appropriate indicator to represent accumulated knowledge has always been a predicament. Scientometrics[3] provides us with the tools to measure knowledge as research output in a country. This brief literature review focuses particularly on studies using scientometric indicators and also highlights the advantages and disadvantages of using these indicators.

De Moya-Anegon and Herrero-Solana (1999) found significant correlation between the GDP of Latin-American countries (1995) and the number of articles in journals indexed in the Science Citation Index (SCI) (1996). King (2004) described an exponential relation between "wealth intensity" (GDP per capita) and "citation intensity" (citations per GDP) for 31 countries. Vinkler (2008) and Lee et al. (2011) both suggest that the nature of the link between research and economic growth varies depending on the development stage of the respective country and its particular emphasis on various scientific disciplines. For the developed countries, they find that there is no significant correlation between economic performance and research performance. In contrast, for developing countries the correlation between economic performance and research performance is significant.

In this type of study, the measurement of both economic growth and research output are of utmost importance. Although measuring economic growth is straightforward (Gross Domestic Product (GDP) is the most commonly used indicator), measuring the capacity of knowledge or research output in a country is not as simple. Scientometric analysis is considered one of the most objective and straightforward ways of measuring innovation and research performance of a country, a region or an institution (Pouris & Pouris, 2009). Nevertheless, other past efforts have preferred input indicators for the measurement of knowledge stock such as R&D expenditures (Fedderke & Schirmer, 2006). Research output indicators are more robust than input indicators. For example, R&D expenditures are collected through surveys which are neither repeatable nor verifiable

3 "Scientometrics can be defined as the system of knowledge which endeavours to study the scientific system with the use of definite methods: observation, measurement, comparison, classification, generalisation and explanation. To use a parallel, scientometrics is for science what economics is for the economy. Both disciplines attempt to study social phenomena with the rigour provided by the scientific methods" (Pouris, 1994).

exercises. In contrast, analysing research outputs is a repeatable and verifiable exercise. Moreover, output indicators convey more information than inputs indicators. Resources may be spent for research and development without bringing any useful outputs as a result. For these reasons, our analysis focuses on the scientometric literature and the output indicators used therein.

Scientometric analysis is based on two types of indicators: bibliometric and patent indicators. The use of bibliometric indicators is considered a more conclusive measurement of research activity and expertise because it includes the research output from fields of science that do not necessarily produce patents such as social sciences, humanities, law and others. Many inventions are not patented due to entry barriers, other measures of protection or because the inventors believe in the profitability of the patent regardless the existence of possible imitators in the future (Pouris & Pouris, 2009).

The main bibliometric indicator used in the literature is the number of publications produced by the entity under investigation. Price (1978) states that “for those who are working at the research front, publication is not just an indicator but in, a very strong sense, the end product of their creative effort”. For comparison purposes, the research publications of a country or an institution are considered good proxies of scientific manpower and knowledge accumulation (Schubert & Telcs, 1986). This is especially helpful in an analysis of developing countries, such as South Africa, that lack sophisticated monitoring mechanisms of science, technology and innovation.

An indication of the relative quality of the research publications is the number of citations for each paper. A number of authors have used citation analysis for evaluation purposes (Haiqi & Yuha, 1997; Butler, 2003; Pouris, 2003). However, potential drawbacks of this indicator are the possibility of the author self-citing his or her own papers in future research, articles from developing countries not receiving visibility equal to developed countries, and similar aspects. Thinking a step ahead, the link between economic growth of and the growth in the number of publications in a country should be measured vis-à-vis the research performance of the rest of the world. It is research and innovation performance vis-à-vis the rest of the world that may lead to economic growth. For this reason, we prefer to use the share of South African publications in relation to the rest of the world as an indicator of the country’s growth in research performance and knowledge accumulation. Furthermore, such an approach neutralises the fact that Thomson Reuters, in their indexing efforts, changes the set of journals indexed from time-to-time.

There is also a number of studies which use the research output in specific fields as an indicator of research performance of a country. For example, Hart and Sommerfeld (1998) examined the relationship between economic growth and the growth in chemical engineering literature – but not the total literature. As is argued in their paper, "the field of chemical engineering, perhaps because of its small but well defined area of technical endeavour, is often used in the performance of scientometric and science policy studies" (Hart & Sommerfeld, 1998:300). However, bibliometric assessment of research performance is based on one important assumption: the work that is evaluated must be published in open, international journals. This means that other fields of science are also appropriate such as the natural and life sciences. In the applied and engineering sciences as well as in the social and behavioural sciences and in the humanities, international journals are often not the primary communication channel. If this is the case, bibliometric assessment becomes problematic. However, in fields like chemical engineering, psychology and even linguistics (Nederhof & Noyons, 1992) bibliometric analysis can be applied successfully. For instance, we observe a striking increase in recent years of publications in international journals for the social and behavioural sciences as well as for the humanities in the Netherlands (Van Raan, 1996).

Effort has previously been made to examine the relationship between research performance and economic growth for South Africa. For instance, Fedderke and Schirmer (2006) approached the topic only for the manufacturing sector by using expenditures on R&D for the period 1970–1993. Their analysis concluded, among others, that there were "...positive pay-offs in terms of output growth, investment performance as well as efficiency gains" (Fedderke & Schimer, 2006:149). This was particularly evident in the period 1970–1983 and it was highly industry-specific.

3. Research methodology

Economic research has extensively used co-integration techniques in order to examine the long-run relationship between variables. Through the years, numerous tests and techniques have been used for that purpose, such as the Engle-Granger residual-based test (1987) and the Johansen's system based rank regression approach (1991, 1995). For all of these techniques, knowing the order of integration of the series is imperative and the formal tests for defining it lack certainty of results.

The methodology used here is the autoregressive distributed lag (ARDL) method as it was proposed by Pesaran and Shin (1999). This methodology does not require prior knowledge of the order of integration of the variables. "The statistic underlying the procedure is the familiar Wald or F-statistic in a generalised Dicky-Fuller type regression used to test the significance of lagged levels of the variables under consideration in a *conditional* unrestricted equilibrium correction model (ECM)" (Pesaran, Shin & Smith, 2001).

As Narayan (2005) points out, the ARDL method is efficient for the following three main reasons:

1) Large samples are not a prerequisite for the estimation.

2) It estimates the long-run and short-run components of the model simultaneously.

3) It is able to differentiate between dependent and independent variables.

Assuming that we want to examine the long-run relationship between Y_t and X_t and there is no prior information on the direction of the relationship, the following error correction equations are estimated dealing with each of the variables as a dependent one in turn:

$$\Delta lnY_t = \alpha_{0Y} + \sum_{k=1}^{n} B_k \Delta lnY_{t-k} + \sum_{k=0}^{n} C_k \Delta lnX_{t-k} + \delta_1 lnY_{t-1} + \delta_2 lnX_{t-1} \quad (1)$$

$$\Delta lnX_t = \alpha_{0X} + \sum_{k=1}^{n} B_k \Delta lnX_{t-k} + \sum_{k=0}^{n} C_k \Delta lnY_{t-k} + \delta_1 lnY_{t-1} + \delta_2 lnX_{t-1} \quad (2)$$

Where Δ denotes the first difference operator and n the number of lags selected.

In this study, in order to select the optimal number of lags, a simple vector autoregressive model of the two variables is estimated. A number of criteria will be taken into consideration such as the Akaike Information Criterion (AIC), the Schwarz Information Criterion (SIC), the Hannan-Quinn (HQ) and the Final Prediction Error (FPE).

The F-tests of these estimations are used to test for the long-run relationship. If the long-run relationship exists, the F-test shows which variable should be normalised. The null hypothesis of the test is no co-integration H_0: $\delta_1=\delta_2=0$ against the alternative of co-integration H_1: $\delta_1 \neq \delta_2 \neq 0$.

Pesaran et al. (2001) and Narayan (2005) developed two bounds of critical values where the upper bound applies when all variables are integrated of order 1 and the lower when all of them are stationary. Ziramba (2008) explains that if the F-stat for a specific level of significance lies between the two bounds, then no conclusion can be made with regards to co-integration. If it is higher than the upper bound [smaller than the lower bound], the null hypothesis of no co-integration cannot [can] be accepted and hence the conclusion is that there is co-integration [no co-integration].

For this study equations (1) and (2) will become:

$$\Delta lnGDP_t = \alpha_{0GDP} + \sum_{k=1}^{n} B_k \Delta lnGDP_{t-k} + \sum_{k=0}^{n} C_k \Delta lnRES\_OUT_{t-k} + \delta_1 lnGDP_{t-1} + \delta_2 lnRES\_OUT_{t-1} \quad (3)$$

$$\Delta lnRES\_OUT_t = \alpha_{0RES\_OUT} + \sum_{k=1}^{n} B_k \Delta lnRES\_OUT_{t-k} + \sum_{k=0}^{n} C_k \Delta lnGDP_{t-k} + \delta_1 lnGDP_{t-1} + \delta_2 lnRES\_OUT_{t-1} \quad (4)$$

Where GDP is the Gross Domestic Product; RES_OUT is the research output as a share of South African publications in relation to the rest of the world; *ln* symbolises the natural logarithm and Δ the difference. If there is co-integration detected in equation (3), the conclusion would be that the share of SA publications in relation to the rest of the world causes changes in economic growth. On the other hand, if co-integration is detected in equation (4), it would mean that the economic growth of the country causes changes in the share of SA publications globally. Using the ARDL methodology to establish the direction of the causality among variables is common practice in the literature, for example Narayan (2005), Narayan and Narayan (2005), Ziramba (2008) and Amusa et al. (2009).

The same pair of equations will be used for the relevant estimation for various fields (biology and biochemistry, material sciences, physics, psychiatry and psychology). The reason for the estimation of these fields of science is two-fold. Firstly, this exercise is done for robustness purposes of the econometric application. But most importantly, we want to investigate whether the mechanism (as was proposed in Figure 1) holds for individual fields of science. Showing that this relationship holds for a number of fields will enhance the proposal of policies with regards to the academic research activities. In the regressions, the only difference that the variable RES_OUT will now indicate the share of SA papers in relation to the rest of the world for the specific field. Again, the F-statistic of the first equation will be called F_{GDP} and for the second F_{RES_OUT}.

It should be noted here that the analysis is primarily bi-variate. The intention of this choice is to only focus on the relationship between the two variables in question. We acknowledge the fact that there are other variables that might affect their interaction. For this paper, however, we concentrate on the direct possible influence of the one to the other.

4. Data

The two main variables needed for the analysis are the Gross Domestic Product (GDP) of South Africa and the share of SA publications in relation to the rest of the world (both for the total and the individual fields mentioned).

The South African GDP is derived from the *Quarterly Bulletin* of the South African Reserve Bank (SARB, various issues) as it is presented in the SARB's online databases. It is employed in constant 2005 prices in order to avoid the impact of price fluctuations and the unit of measure is ZAR millions.

For the second important variable of the analysis, a number of specialised databases are usually employed in the literature, such as Chemical Abstracts, Compendex, Embase and others. In our analysis, the Institute for Scientific Information (ISI) Thomson Reuters family of databases is employed. In the National Science Indicators database, the ISI counts articles, notes, reviews and proceeding papers, but not other types of items and journal marginalia such as editorials, letters, corrections, and abstracts (Inglesi-Lotz & Pouris, 2011).

The database's multidisciplinary and interdisciplinary character makes it the best available option to derive such information from. In addition, the database covers the most influential and important journals in the worlds in all fields, thus ensuring a certain high level of quality of research. For the South African research environment, the ISI database are particularly important as is illustrated by the fact that the Department of Education has recognised the ISI indexed journals for higher education subsidy purposes.

The database includes more than 6 000 peer-reviewed journals in all fields of research (see Table 1).

Table 1 Fields of research included in ISI database

Fields		
Agricultural sciences	Environment/ecology	Neuroscience and behaviour
Arts and humanities	Geosciences	Pharmacology and toxicology
Biology and biochemistry	Immunology	Physics
Chemistry	Materials science	Plant and animal science
Clinical medicine	Mathematics	Psychiatry/psychology
Computer science	Microbiology	Social sciences, general
Economics and business	Molecular biology and genetics	Space science
Engineering	Multidisciplinary	

Figure 2 shows the number of published papers in South Africa from 1981 until 2010 as well as the share of South African papers in relation to the rest of the world. Both present an upward trend through the years that becomes substantially steep from the beginning of 2000 onwards. Pouris (2012) identifies the primary incentive fuelling the recent growth as the new funding formula in the country which subsidises universities by more than R100 000 for each publication that their staff produces.

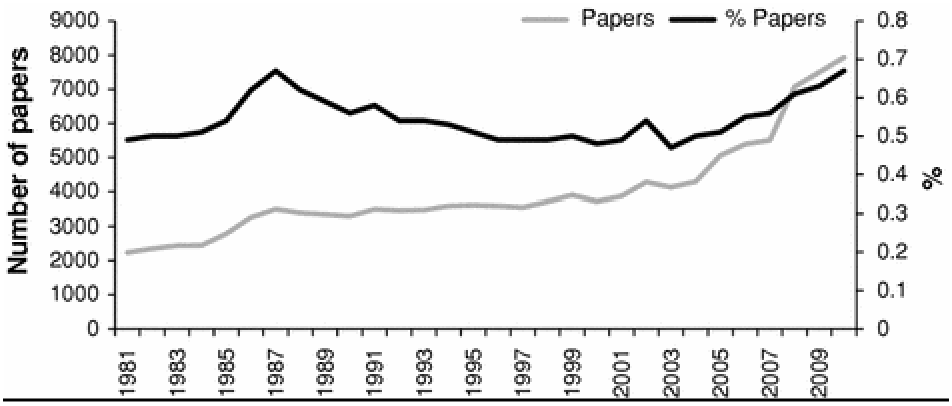

Fig. 2 Number of publications in South Africa and share of SA in relation to the rest of the world publications

Although information on GDP and the scientometric variables are available until 2010, the sample selected for this paper ends at 2008. This is mainly to avoid the period of the global financial crisis. During these years, the GPD growth was affected severely by factors other than the countries' scientific performance. Also, the publication trend might have changed negatively not due to differences in the researchers' behaviour but rather to alterations in the funding for R&D.

5. Results

The lag length selection should be determined before the actual estimation of the ARDL model. We used a group of different criteria as discussed in Section 3. The optimal number of lags for the estimation with the total share of publications is 1 while it varies for the various fields.

Table 2 presents the results of the ARDL model for the estimation with the SA share of publications of all fields in relation to the rest of the world. Panel A reports the critical values as estimated by Narayan (2005)[4]. Panel B presents the F-statistic for the two equations [F_{GDP} for GDP being the dependent variable and F_{RES_OUT} for RES_OUT being the dependent variable]. From this panel, we can see that only F_{GDP} is statistically significant at a 5% level of significance since it is higher than the upper bound of the critical values at this level of significance. However, the F_{RES_OUT} is statistically insignificant. The results can be interpreted as follows: There is a one-direction causality showing that changes in the comparative research performance of South Africa can affect changes in

4 Both Pesaran et al. (2001) and Narayan (2005) generated critical values for the specific non-standard F distribution. However, Pesaran et al. (2001) used samples of between 500 and 1 000 observations while Narayan (2005) used smaller samples of between 30 to 80 observations. Given that our sample is a relatively small one, the Narayan (2005) critical values are preferred.

the economic growth. However, for the same period, economic growth cannot influence the research output of the country.

Table 2 Results of ARDL for relationship between GDP and share of SA publications in relation to the rest of the world (all fields)

Panel A: Critical values according to Narayan (*2005*)						
Critical values	**1 %**		**5 %**		**10 %**	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
	8.17	9.285	5.395	6.35	4.29	5.08

Panel B: Results of ARDL tests for the existence of a long run relationship		
F_{GDP}	6.463	**
F_{RES_OUT}	2.182	

Table 3 Results of ARDL for relationship between GDP and share of SA publications in relation to the rest of the world (various fields)

Panel A: Critical values according to Narayan (*2005*)						
Critical values	**1 %**		**5 %**		**10 %**	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
	8.17	9.285	5.395	6.35	4.29	5.08

Panel B: Results of ARDL tests for the existence of a long run relationship		
	F_{GDP}	F_{RES_OUT}
Biology and biochemistry	7.515**	3.701
Chemistry	5.325*	2.083
Material sciences	5.089*	1.297
Physics	6.053*	1.536
Psychiatry and psychology	6.124*	1.689

* Statistically significant at 10 % level of significance

** Statistically significant at 5 % level of significance

*** Statistically significant at 1 % level of significance (where applicable)

Table 3 presents the results of the ARDL model for the estimation with the SA share of publications of various fields in relation to the rest of the world. Panel A reports the critical values as estimated by Narayan (2005). Panel B presents the F-statistic for the two equations [F_{GDP} for GDP being the dependent variable and F_{RES_OUT} for RES_OUT being the dependent variable] for all the fields of science identified earlier. From panel B, we observe that F_{GDP} is statistically significant for all fields since it is higher than the upper bound of the critical values, at the 10% level of significance (with the exception of 'biology and biochemistry' where the F_{GDP} is statistically significant at the 5% level of significance). However, the $_{RES\_OUT}$ is statistically insignificant in all cases. This confirms the previous result of a one-direction causality from the comparative research performance of the country to economic growth and not vice versa.

6. Discussion and Conclusion

The purpose of this study was to examine the relationship between research output and economic growth in South Africa for the period 1980–2008. It is argued that improvement in research output is the manifestation of improvement in the quality of human capital and accumulated new knowledge. Using the ARDL method, we investigated more specifically the relationship between economic growth measured by GDP and research output measured by the comparative performance of the country to the rest of the world (share of South African papers in relation to the rest of the world). For robustness purposes, we also examined the same relationship for particular fields of science to have a better picture of the mechanism.

The results of this exercise showed that for the period 1980–2008, the comparative performance of the academic research output in South Africa could be considered as a factor affecting the economic growth of the country. However, the opposite does not hold: economic growth did not influence the research productivity of South Africa. This was also confirmed for the various specified scientific fields.

The causality from research to economic growth is of importance not only for scientometric purposes – linking scientometrics with econometrics and economics – but also for science policy purposes. Evidence that the research undertaken in a country is appropriate and can fuel economic growth may be a powerful argument for the science and technology community in its quest to raise scarce resources. Undoubtedly, there are different ways that various scientific disciplines interact and affect economic development. For example, development based on the pharmaceutical industry requires substantial basic research and risk capital. Development based on engineering products, on the other hand, requires less basic research and (from the example of the East Asian countries) more expertise in reverse engineering and accommodating intellectual property regime (Pouris & Pouris, 2011). Consequently, if the causal relationship between research outputs and economic growth can be established it can be argued that the research undertaken in the country, as it is manifested in the country's publications, is appropriate for and contributes to economic growth.

Our study confirms the results of Vinkler (2008) and Lee et al. (2011) and sets South Africa in the domain of the developing countries. It can be argued that, for as long as this directional causality lasts, the science and technology authorities should maintain and increase their support to the research community. Lee et al (2011) suggest that the selection of priority areas for research is an important matter for a state and they refer to suggestions that some areas of research may have a greater impact on economic development than others, that under-developed nations should focus their research investment in the areas of education, infrastructure and engineering and that the East Asian tigers were successful in engineering based disciplines. Undoubtedly these arguments provide interesting topics for further research: Questions like whether scientific disciplines should be linked to the country's economic planning; whether emphasis in different scientific disciplines has identifiable impact on economic growth; or whether the East Asian tigers paradigm is applicable to other countries and similar provide interesting directions for investigation.

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