Ref: JTRG_2019_1009

Title: The evolutionary path of automobility in BRICS countries

Journal: Journal of Transport Geography

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Word Count:6 994 words incl. 4 tables + 6 figures, excluding Acknowledgement and References

First version submitted [31 December 2019]; Revision submitted [23 March 2020]

ABSTRACT

Projections indicate that global transport may more than double by 2050. Future car stock and use are of paramount importance for drafting policy measures and for assessing emerging technology developments. This paper uses a unique forecasting approach combining quantitative data and qualitative expert judgements. Based on the historic development of vehicle kilometers traveled (VKT) in four OECD countries, the approach assesses potential future development paths for BRICS countries (Brazil, Russia, India, China and South Africa) and derives VKT saturation levels for these. For this purpose, we investigated eight factors with influence on car ownership and car use. A group of experts established factor values for the BRICS countries and compared these to the factor values in the OECD countries. Subsequently, we linked the factor values to levels of car use. Among the BRICS countries, we expect the lowest VKT saturation levels for India and China, mainly but not exclusively due to their spatial structures and transport policies. Spatial structures, socio-economic legacies and policies, among other factors, are leading to higher expected VKT saturation levels in Brazil, Russia and South Africa. Those countries also face challenges to establish alternatives to the private car.

Keywords: vehicle kilometers traveled, private car use, transport demand, BRICS countries, emerging economies.

INTRODUCTION

The demand for passenger transport is expected to increase substantially as economic growth continues in countries around the globe. Both, the International Transport Forum (ITF) and the International Energy Agency (IEA) expect global passenger transport to more than double between 2005 (ITF) or 2015 (IEA) and 2050 in baseline scenarios (ITF 2017, IEA 2009). Despite such global estimates, specific projections of passenger transport demand for countries worldwide are rare.

Projections of future car use, or more common future automotive energy use, are mostly based on the development of population, income as proxied by gross domestic product per capita (GDPpc) and costs for fuels and technology (compare e.g. WEC 2011, IEA 2016, ITF 2017). Since data on vehicle kilometer traveled is rare, those models usually approach the energy demand by estimating the number of cars and assuming their use.

Dargay et al. (2007) modeled the development of vehicle ownership rates based on historic patterns for 45 countries. According to this data, car ownership exhibits a dynamic motorization phase once income starts to rise, and levels off when a certain threshold of income has been reached. This S-shaped curve and the tendency of saturation are visible for high-income countries. Low- and mid-income countries may have entered the dynamic motorization phase, but have not yet reached saturation.

These approaches for projecting car ownership and energy demand apply statistical modeling and draw on quantitative data. One of the challenges of such methods is the lack of data and their questionable comparability and reliability. In some cases (e.g. vehicle kilometers traveled) desired data is missing completely for many countries, in other cases it follows non-uniform standards, for example urbanization data by the United Nations. Another challenge of such purely quantitative projections is differences in saturation levels that cannot be explained by economic factors. Dargay et al. (2007) countered this by including factors for population density and urbanization rates in the Gompertz function. An Australian approach integrated unemployment figures into the modelling (BITRE 2012).

Against the observation that car ownership and car use cannot be explained by economic parameters alone, Ecola et al. (2014) established an approach for deriving future levels of passenger car use (labeled “automobility”) that combines both quantitative and qualitative elements. They applied this approach in their study “The Future of Driving in Developing Countries” (Ecola et al. 2014) for estimating future car travel in Brazil, Russia, India, and China. This approach also builds on the S-shaped development of car ownership and a set of external framework conditions define the automobility path for a specific country. The economic development, however, is key to how rapidly the country proceeds on this path.

After five years, the paper at hand presents an update of this 2014 study. This follow-up study broadened the first study: firstly, we applied updated statistics and integrated additional data; secondly, we added South Africa to the list of countries to be examined. The update of the study was conducted by a research team that was partly identical to that of the first study, and we gratefully acknowledge the foundation that was laid by all authors around Ecola et al. (2014). Both studies involved a largely identical group of international experts, who represented the study countries and contributed to the assessment.

DATA AND TRENDS IN FOUR OECD COUNTRIES

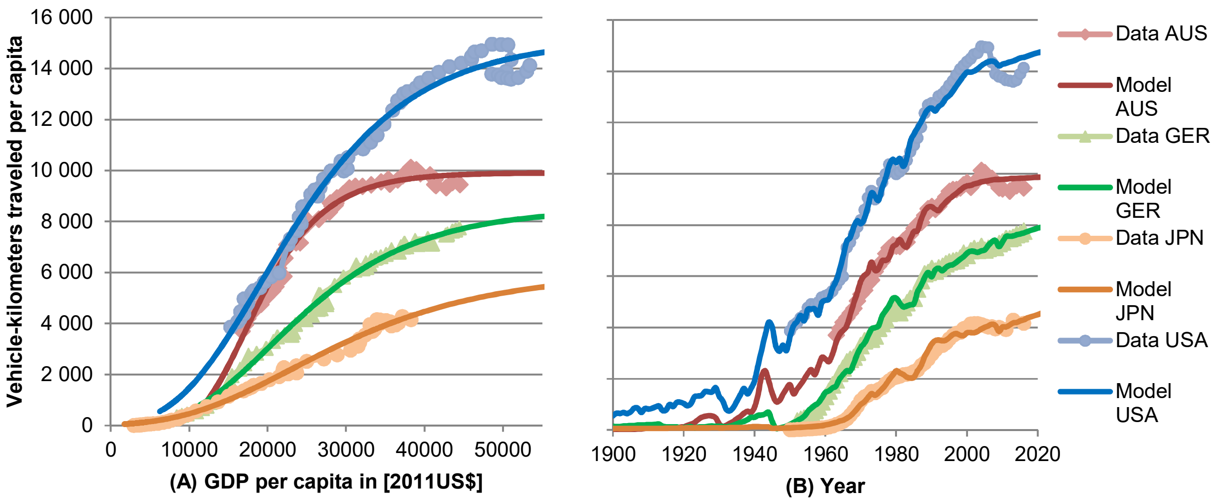
Analogous to Ecola et al. (2014), we have selected four OECD countries (Australia, Germany, Japan, and the United States) that represent the reference for the projection of automobility in BRICS countries. Our reasons for the selection are: (i) all four countries have achieved a high level of income, expressed as GDPpc, (ii) in all countries tendencies of saturation of automobility are apparent, (iii) the countries are located on different continents and thus represent a wide range of geographic conditions, and (iv) have different socio-economic and cultural backgrounds. We thus draw conclusions from the development patterns in these countries and extrapolate them to the BRICS countries. The plotting of VKT over GDPpc, using Gompertz functions, reveals a good correlation between these two variables, but also shows the different saturation levels not explained by GDPpc.

For the calculation of VKT, we applied a simple Gompertz function comparable to that of Dargay et al. (2007):

$$VKTi = \gamma\, e^{-\alpha\, e^{-\beta\, GDPi}}$$

where γ is the saturation level and α and β are negative growth rates, defining the shape of the curve. Plotting modelled and observed VKTpc over GDPpc values (**Figure 1**) illustrates that the model maps the historic development reasonably well (estimated values γ, α and β and there standard deviation are presented in the appendix)..

Figure 1 Development of VKT (A) over GDP per capita and (B) over time, based on real data (Data) and Gompertz function (Model). Own depiction. *[online in color]*



The update of the 2014 study results in slightly different automobility patterns for the four OECD countries compared to Ecola et al. (2014). Most notably are lower VKT saturation levels for all four OECD countries (values see **Table 1**). Our recalculations and updates are based on national and international statistical figures for GDP, GDP per capita (GDPpc) and car use (VKT, expressed as vehicle kilometers traveled per capita) up to the year 2017. Similar to the previous study, the most dynamic motorization period lies between 10 000 and 35 000 $US\$_{2011PPP}$ GDPpc [1].

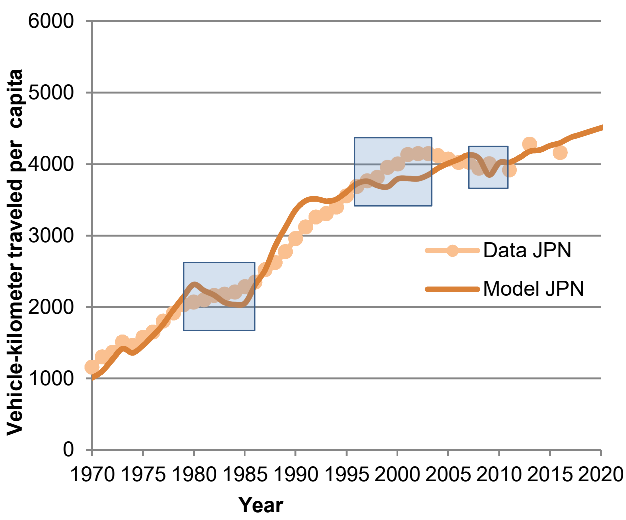
[1] While Ecola et al. (2014) used the 1990 Geary-Khamis Dollar, we updated the GDPpc figures based on data by the World Bank (2019), which provides figures in 2011 International US Dollars, normalized to purchasing power parity (PPP). The absolute GDP values are thus higher than in the previous study.

Table 1 Comparison of VKT saturation levels of the updated analysis compared to the former study (Seum et al. 2019)

	VKT saturation levels [km per capita]	
Country	**According to Ecola et al. (2014)**	**Study update 2019**
Australia	10,800	9,900
Germany	9,700	8,500
Japan	6,400	6,000
United States	16,300	15,100

Our update shows that the economic crisis in 2008/2009 has led to changes in the model fitting. With declining income, a reduction of VKT can be observed, except for **Germany**. Particularly the **United States** had seen a declining GDPpc, coupled with a decline in VKT. Since 2012, income and the VKT in the USA are increasing again. **Australia** and **Japan** also saw a decline in VKT during the recession years and both seem to have leveled off. In **Germany**, the recession had not dampened VKT, and the saturation level apparently has not been reached yet.

Figure 2: Comparison of VKT data with Gompertz-calculated VKT data for Japan, years 1970 – 2020. The squares highlight periods of economic recession with further increasing VKT according to statistical data *[online in color]*



The Gompertz function for Japan predicts a continuously increasing VKT, even beyond 35 000 GDP per capita and resulting in a saturation value of approximately 6 000 VKT However, from the year 2000 onward there were clear tendencies of VKT-saturation in Japan which are not reflected well in the model prediction. Likely reasons for this are inadequate representations of continued growth of VKT during previous times of economic recessions in the model, a time trend independent from GDPpc growth (Figure 2) as well as inconsistencies in the Japanese VKT statistics over time. While some continued growth of VKTpc for Japan seems likely, an increase to 6000 km appears unlikely given the countries historic development relative to other countries. Having to decide on a plausible saturation level for the next steps of the project, we opted for 4,500 km. This value is based on the future saturation rates of the other study countries and Japan's position relative to these countries today

METHOD OF THE FLAG-GAME APPROACH

As stated above, our study combines statistical analysis with qualitative assessments. The main reason behind this approach is that statistical figures on GDP and the demographic development are not sufficient to explain the level of automobility in a country. Ecola et al. (2014) had identified nine factors that characterize the future path of automobility. Out of these, we kept eight factors in the study update to predict VKT. The ninth factor – domestic oil – was shifted to a separate part of the analysis that addresses the evolution of propulsion technologies. This second part, however, is not the subject of this paper.

The eight factors are:

- *Active population*: The share of the population at a stage in life that is characterized by high mobility rates.
- *Domestic car industry*: The relevance of a *domestic car industry* for the national economy.
- *Spatial dispersion*: The extent to which settlement patterns are conducive to automobility.
- *Car culture*: The country's affinity to cars from a socio-cultural perspective.
- *Car infrastructure*: The entire infrastructure for driving, including quality and quantity of roads, parking, and level of service.
- *Inexpensive driving*: Low expenses for driving (including taxes) relative to income.
- *Pro-car policies*: Policies and legislation directed to promote car ownership and usage.

- *Lack of alternatives*: How car-focused the transport system in a country is, particularly with regard to infrastructure available for other modes of urban and interurban travel.

For our analysis of the eight factors, we use indicators derived from statistics and combine these with a qualitative assessment in a workshop format called “flag game”. The flag game was conducted during a two-day workshop, held in October 2018, that brought together fourteen experts, two from each BRICS country and one each for Australia, Japan, Germany, and the United Sates (Kuhnimhof et al. 2014). Based on indicators and literature review, we compiled brief fact sheets for each factor as input for the expert discussion. During the flag game, the experts then determined the flag position of each country relative to the four OECD countries for each factor(**Figure 3**). The method thus combines numeric information with judgement from international experts with long histories of observing trends and developments. Relying on expert judgement carries a burden of subjectivity (Niederberger & Wassermann 2015). However, the use of expert judgement is common in policy consultations and an essential element of future studies. Alcamo (2008) argues that pure quantitative approaches often provide a false sense of the future due to the lack of exactness of numeric data. Furthermore, building on numeric data predictions into the future contains many implicit assumptions as well (Alcamo 2008). In our exercise of the flag-game we tackled the aspect of subjectivity in two ways: first, our selection of experts relied on persons that dispose of significant contextual knowledge in the field of transport development in their own, but also in other countries. Thus, our experts explicitly are observers of a scientific field without personal interest in it (A comprehensive discussion on the role of experts can be found in Niederberger & Wassermann 2015). Second, the positioning of the flags was conducted in a consensual approach. Thus, while the aspects of subjectivity cannot be removed from this approach, it is likely that a similar group of experts in the future would not deviate drastically from the judgements made in our exercise. The following statements rest on the discussions during the workshop. Following the Chatham-house rule, without attributing it to a specific person. Other input is marked with a literature reference.

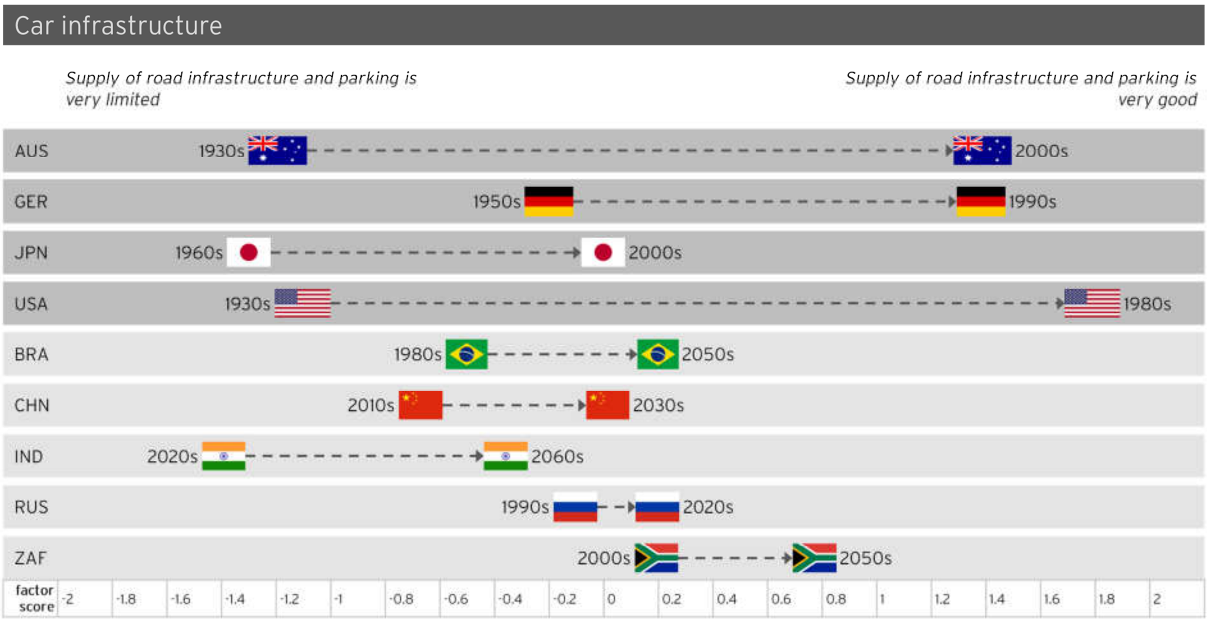


Figure 3 Flag game results for factor *car infrastructure* as example. *[online in color]*

The flag game visualizes for each factor, to which degree it encourages or impedes the development of automobility. For each country two flag positions were established: the first position indicates the factor situation at the early stage of motorization in the respective country (approximately at 10 000 $US\$_{2011PPP}$ GDPpc); the second position marks its situation at the point in time, when the growth of automobility starts to level off (the saturation phase, approximately at 35 000 $US\$_{2011PPP}$ GDPpc). The national GDPpc levels are based on time series data for 1990–2017 (Word Bank 2019), complemented up to 1990 by historical GDP values (Bolt et al. 2018) and for the years 2017 onward by extrapolated data using GDP growth rates of an OECD model (IIASA 2016). Since for all BRICS countries the beginning of the saturation phase lies in the future, these flag positions relied on estimates of our country experts. We then converted the flags' positions into a scale of values ranging from -2 to +2, where -2 correlates with impeding and +2 with promoting automobility in a country.

In a second step, country experts were asked to judge the comparative weight of each factor with regard to VKT. In the end, an automobility score (AS) is calculated for each country, as weighted average of all eight factor scores. The AS serve as proxy to estimate the saturation levels for VKT and car ownership for each country. Each participating expert could vote with a weighting number one, two or three on the significance of each factor for VKT and car ownership. The weighting was set comparatively. The final factor weight per factor represents the simple average of all votes. There was a strong agreement particularly on the factors with high weight: *urbanization* and *spatial dispersion*, *car infrastructure* and *lack of alternatives* as well as on *active population* to have a strong influence on the VKT. The weightings for *domestic car industry*, *inexpensive fuel* and *car culture* were definite, but with some spread, whereas the impact of *pro car policies* for VKT was inconclusive. Whether the factor weighting have a significant impact on the outcome will be discussed later.

SUMMARY OF SELECTED FACTORS WITH HIGH INFLUENCE ON AUTOMOBILITY

Table 2 lists all factor scores for the OECD and BRICS countries for the corresponding points in time, where countries reached - or are projected to reach - 10 000 and 35 000 US$$_{2011PPP}$ GDPpc levels. Highlighted are scores that represent the upper (green) or lower (red) 20% in each column. Those for the points in time when the country is reaching the saturation phase of automobility are highlighted in bold. The last row shows the weights assigned by the expert panel to each factor with regard to VKT (the higher the score, the more in favor of automobility).

Table 2 Factor scores and factor weights based on the flag game exercise for the beginning of the motorization phase and the beginning of the saturation phase. Factor weights are provided in the last row. *[online in color]*

Country	Decade when GDPpc reached 10,000 and 35,000 US$	Active population	Spatial dispersion	Domestic car industry	Car infrastructure	Lack of alternatives	Pro car policies	Inexpensive driving	Car culture
		Factor scores							
Australia	1930s	0.1	-0.8	-0.8	-1.2	0.1	1.2	0.5	0.4
	2000s	0.9	**1.8**	-0.1	**1.4**	**0.9**	0.6	**0.9**	0.3
Germany	1950s	-0.5	-1.3	0.9	-0.2	-0.9	0.1	-1.0	0.2
	1990s	0.4	-0.5	**1.8**	**1.4**	**-1.5**	-0.5	-0.3	-0.1
Japan	1960s	0.4	-1.8	0.7	-1.3	-0.8	0.5	-1.1	0.0
	2000s	0.0	-0.9	**1.6**	0.0	**-1.5**	**-1.2**	-0.2	**-0.3**
United States	1930s	0.4	-0.8	1.4	-1.1	0.1	1.8	1.3	1.6
	1980s	0.9	**1.7**	0.4	**1.8**	**1.5**	0.9	**1.7**	**0.9**
Brazil	1980s	0.9	-0.2	0.7	-0.5	-0.1	0.9	-1.0	0.3
	2050s	1.1	0.3	1.3	0.2	-0.4	0.6	-0.6	**0.9**
China	2010s	1.3	-1.7	0.4	-0.7	-0.5	-0.1	-1.0	-0.3
	2030s	**1.5**	-1.0	1.0	0.0	**-1.7**	**-1.6**	-0.6	0.6
India	2020s	0.6	-1.7	-0.2	-1.4	-0.1	0.3	-1.0	-0.5
	2060s	**1.5**	-0.9	0.7	-0.4	**-1.5**	**-0.6**	-0.6	0.2
Russia	1990s*	0.4	-1.0	-0.2	-0.1	-0.4	1.2	0.3	0.4
	2020s	1.0	-0.3	1.1	0.2	**-1.5**	0.5	-0.2	0.6
South Africa	2000s	-0.6	1.9	-0.8	0.2	1.3	0.9	0.9	0.8
	2050s	**-0.3**	1.4	**-0.2**	0.8	0.4	0.5	0.1	**1.4**
Factor weights for VKT		**2.3**	**2.9**	**1.4**	**2.6**	**2.8**	**2.3**	**2.3**	**1.8**

NOTE: * For Russia, the end of the Soviet Union – 1991 – is considered as starting point.

As a general observation, the factors in favor of automobility dominate in the OECD countries compared to the BRICS countries. Only Japan shows impeding factors (i.e. scoring among the lowest 15%) that dampen automobility in the saturation phase. In Brazil, on the other hand, there is hardly a dampening factor. Otherwise, for the BRICS countries dampening factors dominate. In the following, we will highlight findings from the factors *spatial dispersion* and *lack of alternatives*, the two with the highest factor weights, in more detail and summarize findings of the others thereafter.

Spatial dispersion

Spatial dispersion in a broad sense refers to the spatial and sociodemographic structures in a country. In contrast to Ecola et al. (2014), which used a single value of density in urban areas in the year 2000, we drew from data of the Atlas of Urban Expansion (Angel et al. 2016) a time series of densities of representative urban built-up areas in the study countries (**Figure 4**). Furthermore, we used the share of the population living in cities with more than 300 000 inhabitants (UN DESA 2018) as a second indicator. The dataset provided by Angel et al. (2016) on urban development has identified urban areas representative for geo-cultural regions for the years 1991, 2000 and 2014, thus providing data that allows for the comparison of states and regions and their development over time. The share of population living in cities with more than 300 000 inhabitants is better comparable than e.g. urbanization rates due to different national definitions of the term "urbanization" (UN DESA 2018, p. 2).

Kenworthy (2018) found a strongly inverse relationship between urban built-up density and car use. A drop in urban density below 40-50 inhabitants per hectare results in a sharp increase in car use. This is reflected in the high factor scores for *spatial dispersion*, promoting automobility in **Australia** (37 persons per hectare) and the **United States** (19 persons per hectare in 2014). . It is also noteworthy that the urban built-up density has declined in **all OECD countries**. Hence, the time trend towards increasing *spatial dispersion* favors automobility in **all OECD countries (Table 2)**. High urban population density itself may not be the actual reason for reduced driving in dense urban environment. However, other important factors usually go along with high population densities. This includes reduces needs to travel due to proximity to shopping and other facilities and difficulties to find or afford parking. Hence, historically high urban densities have correlated with reduced automobile travel and this relationship is likely to persist in most instances.

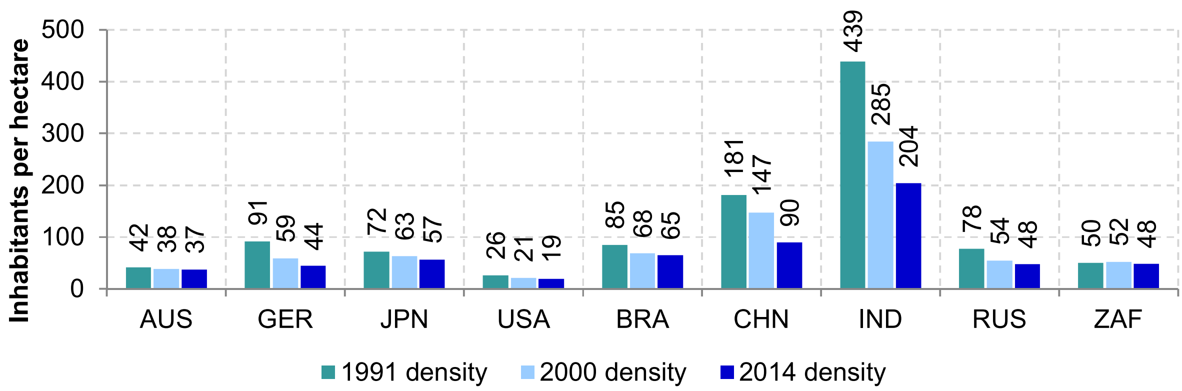


Figure 4 Density of urban built-up areas. Data: Angel et al. (2016). Own depiction.
[online in color]

The **BRICS countries** also show a declining density of representative urban built-up areas, although particularly **China** and **India** starting from much higher levels. This decline is coupled with a strong increase in urbanization, measured as share of population living in cities with more than 300 000 inhabitants. **Brazil** started to convert already in the 1930s from an agricultural economy into an industrialized one (Pojani & Stead 2017). Urbanization is strong and built-up density relatively high (65 inhabitants per hectare). However, the spatial distribution of wealth is very uneven. Today's Brazil knows large marginalized areas for the poor and gated communities for the rich. While residents of gated communities heavily rely on the private car, people of low income regularly have little access to cars. Accordingly, they have to cope with lacking infrastructure for public transport, walking, and cycling that usually is only accessible for a small middle-class in central areas (Pojani & Stead 2017). **China's** proportion of the population living in cities with more than 300 000 inhabitants has doubled since 1990. As cities continue to expand, the density of urban built-up areas has dropped from a notable high of 180 to 90 inhabitants per hectare. People settle increasingly in the suburbs, partly as a result of resettlement policies. Additionally, settlements for migrant workers who cannot afford the cost of living in the central urban areas are emerging around the cities (Pojani & Stead 2017). **India's** relatively large rural population lives in smaller villages. Urbanization is increasing, though with more than 200 inhabitants per hectare Indian cities exhibit the highest densities among the study countries. While the affluent population concentrates in urban centers and planned districts, less privileged people are spreading to the urban periphery and regions outside the cities (Pojani & Stead 2017).

The urban structure of Indian cities favors two- and three-wheelers, nevertheless congestion is a major issue (Verma et al. 2015). **Russia** is still characterized by a period of industrialization during the Soviet era. While the population living in cities with more than 300 000 inhabitants accounts for about 40%, the majority of the remaining population lives in smaller urban settlements around industrial areas of Soviet origin. More recently, a process of suburbanization has taken place, in particular driven by residential choices of Russian elites (Pojani & Stead 2017). The density of built-up areas has declined to less than 50 inhabitants per hectare. Especially since the 2000s, a lack of spatial planning can be observed, with the consequence that housing and economic activities are disintegrating. **South Africa** is the only BRICS country whose spatial pattern is expected to be less conducive for automobility in future years, mostly due to an increasing urbanization and continued high urban density. The spatial structure around cities is fragmented, with residential areas still segregated along the lines of ethnicity and wealth. Typical are radial transport networks (Pojani & Stead 2017), consisting of formal and informal transport services.

Lack of alternatives

The factor *lack of alternatives* refers to absence of alternatives to a private car (the higher the factor, the more inductive to automobility). One number that indicates alternatives to the private car are e.g. journeys of urban public transport per capita (UITP 2017). The data show the differences between the four OECD countries. For the **BRICS countries**, only data for Brazil, China and Russia can be obtained. **Brazil** and **China** show an increasing use of public transportation. In **Russia** the decline in the use of public transport from very high levels reflect the increasing individualism in post-Soviet **Russia** and the deterioration of the formerly ubiquitous public transport system as basic service. Data for India and South Africa are not available. Another indicator used is national passenger kilometers on road versus on rail (ITF 2017).

For the factor *lack of alternatives*, too, it is not sufficient to rely on official figures, as alternatives to the private car can be formal public transport, but also informal services and active modes, for which there are no official figures. For example, UITP (2017) only provides figures urban bus, suburban bus, tram, light rail, metro, and suburban railway operated by official utilities. Informal services are not included, but may play a role in **Brazil** and certainly do in **India** and **South Africa**.

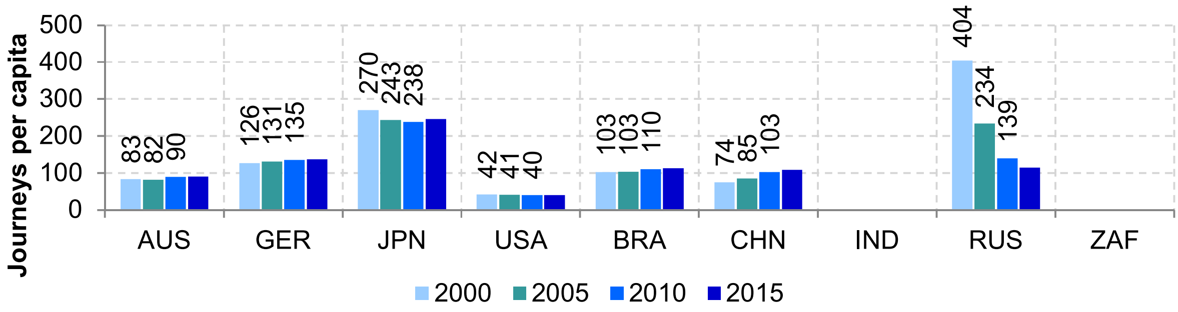


Figure 5 Public transit journeys per capita. Own calculation and depiction based on UITP (2017). *[online in color]*

Among the OECD countries there are two groups: **Germany** and **Japan** show declining and ultimately very low factor scores (see **Table 2**), which corresponds to dampening automobility. In **Germany**, the evenly distributed small- to medium-size cities facilitate a fairly good nationwide supply of public transport. In **Japan**, it is the country's compact settlement structure coupled with high urbanization that favors public transport. While Japan continues to invest in its public transport infrastructure, the German system suffers from austerity measures and therefore has lost some service quality. Accordingly, in Japan 30% of the national passenger kilometers are conducted by rail, in Germany only 9% (ITF 2017). For **Australia** and the **United States** the *lack of alternatives* clearly favors automobility. Although the two countries differ considerably in terms of their public transport services, they have undergone an explicitly car-oriented development. Only in recent years, **Australia** has seen a significant revival of walking and cycling. This is largely stimulated by a trend towards healthier lifestyles and has a diminishing effect on the use of cars. The **United States**, on the other hand, has the lowest level of public transport trips per capita (UITP 2017), which even has declined in recent years. Public transport in the United States is often associated with low-income population and faces concerns related to status and security. New individual transport services further increase the pressure on the public transport system, despite the introduction of some (mostly municipal) programs aiming to promote walking and cycling and investing in rail and bus services.

Brazil has invested significantly into the public transit system in the context of the 2014 Soccer World Cup and the 2016 Olympic Games. However, due to spatial and income disparities, access to transport services differs considerably between population groups. Many marginal areas are poorly served by public transport. Furthermore, the quality of public transport has deteriorated in recent years, leading to a further decline in demand. Besides some informal services, walking and cycling are often the only viable options for many. **China** certainly stands out in its efforts to improve public transport infrastructure, both within urban agglomerations and between cities. The light rail and metro system has expanded substantially in the past decade (Gao et al. 2018), also to reduce congestion that developed due to rapid motorization. Additionally, a resurgence of two-wheelers, including the bicycle in the form of electric or rental bikes can be observed. The provision of urban alternatives to the private car is often combined with regulations restricting ownership and use of private motorized vehicles. Wu et al. (2016) argue that in many metropolitan areas motorization saturation levels have already been reached. China has also made very large investments in national rail. By 2017, 25 000 kilometers of rail tracks connected over 200 cities, mostly in the central and eastern provinces, half of which are designed for high-speed trains. An extension bringing the total to around 38 000 kilometers is planned for 2025 (Bullock et al. 2014). Based on official statistics, VKT by rail equals that of car travel (ITF 2017). In **India**, the predominant public transit is offered as bus services. Metro systems are still at the early stage of development, and construction can barely keep pace with population growth and urbanization. Due to the country's spatial structure, two- and three-wheelers are common alternatives to the car, either privately owned or offered as commercial service. The countrywide rail infrastructure is ubiquitous, but of poor quality. Accordingly, only 13% of the national passenger kilometers are traveled by rail (ITF 2017). Governmental plans aim to improve public transport as alternative to the private car, and therefore it is expected to dampen the development towards automobility. As **Russia** is concerned, public transport was the back-bone of mobility during the Soviet era. Since 1990, the use of public transport has declined dramatically, and income disparities and suburbanization have furthered the infrastructure's deterioration. Only recently, a national strategy aiming to significantly improve the transport infrastructure and services, including high-speed rail, has been put in place (GIZ 2018). Until today, fares are relatively low and this alternative to the private car is still accessible to a large number of citizens. **South Africa** is the only BRICS country with the *lack of alternatives* factor is above zero. Despite attempts by policy and planning, public transportation in South Africa faces concerns with regard to security and comfort resulting in a lack of acceptance. Furthermore, public investments often compete with informal services, mostly mini-buses, and sometimes face fierce opposition.

Summary findings on remaining factor scores

Of the other factors, *active population*, *car infrastructure*, *pro-car policies* and *inexpensive driving* have numeric factor weights above 2.

Active population as the "share of the population in a life stage characterized by high mobility rates" (Ecola et al. 2014: 46) is a very important factor that influences automobility. All **OECD countries** face a shrinking *active population*. However, other aspects such as retirement age, unemployment, or formal and non-formal work need to be considered as well. Additionally, a country's ability to draw positive socio-economic impulses from the population development is relevant. In this context, the World Bank (2016) differentiates pre-dividend, early-dividend, late-dividend, and post-dividend countries. As for the **BRICS countries**, **India** and **South Africa** belong to the early-dividend group, whereas **Brazil**, **China**, and **Russia** belong to the late-dividend group. While early-dividend countries have a huge opportunity to build on their human capital, late-dividend countries face a shrinking *active population*, but have the opportunity to build and secure economic strength by investing their savings to increase the productivity of labor. Prosperity and thus automobility will be adversely affected if a late-dividend country does not succeed in securing labor productivity and assets acquired during earlier periods (World Bank 2016).

Brazil was unable to take full advantage of the opportunities arising from its early-dividend phase and risks to loose its wealth in the late-dividend phase (Berlin Institute 2015). Retirement age is expected to increase and female labor participation is most likely to increase as well. **China** has experienced strong economic growth in recent years and has used its prosperity to invest into productivity gains and to prepare for an ageing society. However, the aging of society increases the likelihood that China will move towards a longer active working life. **India** still belongs to the early-dividend group and thus can prosper, if the creation of productive job can exceed population growth. The share of *active population* is increasing, but female labor participation is rather low and inequality is high. Nonetheless, in regard to the factor *active population*, **China** and **India** are the two countries with the highest factor scores in favor of automobility. **Russia** is a late-dividend country with a shrinking *active population*. To counteract this, Russia is raising the retirement age. Furthermore, labor migration to Russia may play a role in the future. Like India, **South Africa** is one of the early-dividend countries with all its opportunities. As a legacy of the apartheid era, however, the country is struggling with extreme inequality and poverty. Unemployment is high, and life expectancy is comparatively low. South Africa could only benefit from the early-dividend phase if new jobs were created and education and productivity improved at the same time (Schellekens 2016). Its score for the factor *active population* is therefore low.

With regard to ***car infrastructure***, **Australia**, **Germany,** and the **United States** enjoy an excellent road infrastructure. In most areas, parking space is abundant and usually affordable, although particularly **Australia** and **Germany** have begun to focus more on non-auto infrastructure. Compared to the OECD countries, for the **BRICS countries** it is expected that the *car infrastructure* will not have a particularly beneficial effect on automobility.

The factor ***pro-car policies*** shows for all **OECD countries** a shift away from fostering the private car. This is due both to local policies, for example to curb congestion, and to national policies, for example to combat global warming. With the exception of **Japan**, however, none of the **OECD countries** reaches a very low score. For the **BRICS countries** it is apparent that particularly **China**, but also **India** attempt to implement policies that might dampen the use of cars. These policies are implemented to mitigate congestion and to respond to environmental and health concerns. However, in the past, restrictive policies have often been paralleled by policies promoting the ownership and use of cars as a means of economic stimulus. Less political interventions to car ownership and use is observed in the other **BRICS countries.**

With regard to ***inexpensive driving*** (in relation to income), it can generally be observed that driving becomes cheaper in relative terms to income, the more developed the economy is. This holds true for all **OECD countries** and is also supported by statistical data for the **BRICS countries** (compare GIZ 2017). However, the **United States** stands out as the country where automobility is most affordable.

Finally, there are the two factors with a weight below 2: ***domestic car industry*** and ***car culture***. Both probably have a stronger impact on car ownership than on VKT. The ***domestic car industry*** still plays a major role in **Germany** and **Japan**, as it accounts for a large share of the national economy. The score of the **United States** reflects the relative decline of its *domestic car industry* compared to other wealth-creating sectors. Interestingly, for all **BRICS countries** it is expected that the *domestic car industry* will gain relevance, although maybe not to the level of Germany and Japan. However, given the size of the potential markets, this expectation seems quite plausible. The importance of ***car culture*** – i.e. the role the automobile plays in popular culture – is generally declining in the **OECD countries** and increasing in the **BRICS countries**.

AUTOMOBILITY SCORES AND VKT PROJECTIONS FOR BRICS COUNTRIES

Based on the factor scores in **Table 2**, we derived a combined automobilty score (AS) for each country, computed as the weighted average of the single factor scores (**Table 3**, column '**Automobility score VKT'**). As Ecola et al. (2014), we again applied a simple regression analysis, using the VKT saturation levels from the Gompertz function as the explained variable and the combined automobility score as the explanatory variable to derive probable VKT saturation levels for the BRICS countries (**Figure 6**).

The saturation levels of VKT of this study update are generally lower than those of the earlier study (**Table 3**). In particular, the two values for India and China point to increasing policy interventions that will affect both VKT and car ownership.

Table 3 Comparison of automobility scores for VKT, VKT saturation projections from the former study and its update.

Country	Automobility score VKT (weighted average from Table 2)	VKT saturation projection (Ecola et al. 2014)	Updated VKT saturation projection
Australia	0.43	10 800 km	9 900 km
Germany	-0.24	9 700 km	8 400 km
Japan	-0.51	6 400 km	4 500 km
United States	0.87	16 300 km	15 100 km
Brazil	0.20	11 300 km	9 900 km
China	-0.39	7 800 km	6 000 km
India	-0.44	7 000 km	5 700 km
Russia	0.04	10 200 km	8 900 km
South Africa	0.62	NA	12 700 km

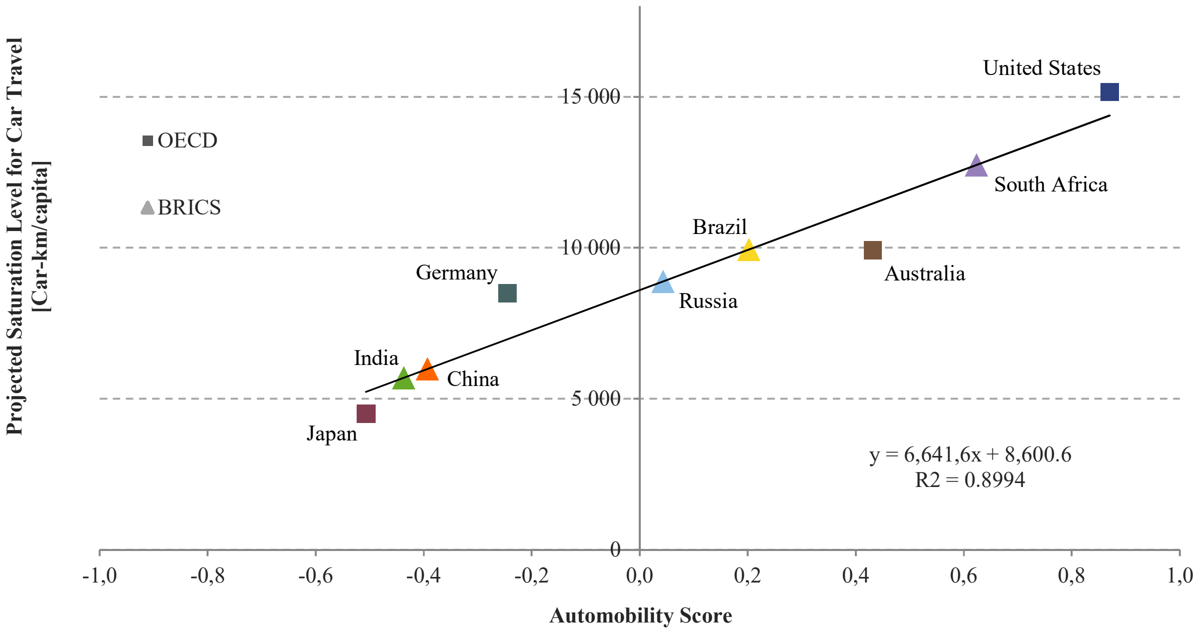


Figure 6 Regression analysis of VKT saturation levels based on country automobility scores. *[online in color]*

We further estimated the effect of the factor weights on the final results, since the factor weights also carry the burden of the participating experts' subjectivity. For this test, we adjusted the factor weights by calculating two extremes: one where the externally (without policy influence) dominated factors *active population* and *spatial dispersion* were weighted high (3) and the policy dominated factors *lack of alternatives*, *pro-car policy* and *inexpensive driving* were weighted low (1); in the second case we reversed the weighting, favoring the policy factors and lowering the external factors. Furthermore a no-weighting case was tested. The resulting VKT of the two extreme cases differ from the reference case between -8% (policy factor dominance China) and +27% (external factor dominance China) (**Table 4**). Most importantly, the order of the countries VKT does not change, although China and India result in similar VKT when considering the policy factors in dominance. Secondly, the expected VKT rises in all countries but South Africa when considering the external factor dominance, indicating a dampening of VKT through policy interventions. This is most pronounced in China, where external factor dominance VKT is 27 % above the reference, compared to 14 % in India for example. For Russia and South Africa the effect of the sensitivity analysis is inconclusive and represents the contradicting influence within the factor categories “external” and “policy” (e.g. *lack of alternatives* dampening car use and *pro-car policy* promoting car use). Overall, the effect of factor weight alterations is limited.

Table 4: Sensitivity analysis of the calculated Automobility Score and VKT, based on the weighting variations.

AS Score	Reference Score	External Factor dominance	Policy Factor dominance
Brazil	0,20	0,33	0,13
China	-0,39	-0,15	-0,47
India	-0,44	-0,32	-0,46
Russia	0,04	0,12	0,09
South Africa	0,62	0,56	0,59
VKT Saturation			
Brazil	9 900 km	10 800 km (+9%)	9 500 km (-4%)
China	6 000 km	7 600 km (+27%)	5 500 km (-8%)
India	5 700 km	6 500 km (+14%)	5 500 km (-4%)
Russia	8 900 km	9 400 km (+6%)	9 200 km (+3%)
South Africa	12 700 km	12 300 km (-3%)	12 500 km (-2%)

In the no-weight test case, the sequential order of the countries remains the same. VKT is generally higher, except for South Africa and the differences are between -4 % (South Africa) to +13 % (China).

DISCUSSION

The automobility scores encapsulate a broad range of conditions that favor or dampen automobility in a single measure. Specifically, the USA features a high automobility score reflecting conditions that are very conducive to automobility. Australia, Brazil, South Africa and to some extent Russia are also leaning towards that extreme. Japan, India and China represent the other end of the range, with Germany trending in that direction. In particular the factors *active population*, *spatial dispersion*, *car infrastructure*, and *lack of alternatives* are responsible for this distinction. The factor *active population* includes more than just the share of the working age population, as it is linked to other socio-economic aspects. Particularly, the economies of Brazil and South Africa are lagging behind their potential, theoretically associated with their dividend phases. *Spatial dispersion* in combination with the *lack of alternatives* also strongly influence the development towards automobility. Certain spatial structures favor automobility, while others at least offer the opportunity to establish alternatives to the private car and thus impede automobility.

It should be noted that particularly for India the spatial structure together with the increasing population has already led to a massive overload of the existing infrastructure and congestion. According to the TomTom traffic ranking, 65% additional travel time is required for Mumbai and 58% for New Dehli due to congestion and the cities rank number one and four in the global 2018 Traffic Index (TomTom 2019). Thus, while this phenomenon is indirectly reflected in the flag game approach, the future development of capacities and potential backdrops with regard to automobility needs further attention. The future of automobility will also depend on the ability to complement income growth with investment in infrastructure. Furthermore, it will be decisive whether infrastructure investments will focus on the public transport infrastructure or on road infrastructure, that way improving the alternatives to the private car. Infrastructure development will also influence the ratio of two-, three-wheelers and passenger cars. In countries with high congestion levels like India, the use of two- and three-wheelers is already high and may increase in the future if road infrastructure cannot keep pace with income growth.

In addition to the above mentioned factors, the factor *pro-car policies* has a significant effect on future development. It can be assumed that the factor *spatial dispersion* affects a country's *pro-car policy*, as policies aim to counter challenges resulting from spatial structures, such as congestion. Other concerns, e.g. the focus on air quality and public health, will lead to regulations and influence *pro-car policies*. The ability to intervene in developments – whether it is infrastructure investments or regulations on vehicle usage – is linked to the countries' governance structures and the appreciation of transport offerings as commons. Particularly China is influencing market development through governmental interventions and large scale state-run investments.

We are confident that our analysis of VKT and car ownership represents a good approximation of the future path of mobility in the countries under investigation. However, as of today, we cannot be certain as to which technologies and business models will be used to serve future transport demand. For example, the widespread use of shared vehicles may considerably reduce the total number of cars needed to meet the anticipated mobility needs. Furthermore, two- and three-wheelers will play an important and potentially increasing role in several countries.

Uncertainties in the predictions are due to the nature of the predictive process and the subjectivity of expert judgements. The different VKT levels of the OECD countries – according to Ecola et al. (2014) on the one hand and our update on the other – result from more heterogenic patterns in the GDP data for the years 2011 to 2017. Hence, it indicates the uncertainties of mathematical approaches originating in data and prediction algorithms. The overall uncertainty of our projections cannot be quantified conclusively and requires ongoing observation of the factors involved.

CONCLUSIONS

The analysis of data on GDP, population and VKT reveals that VKT development and saturation levels cannot be explained by GDP and population alone. The inclusion of other factors provides a sound approach to assess the development of VKT. However, those other factors cannot be analyzed solely by statistical data due to either (i) partly missing data, or (ii) data of uncertain quality and comparability. Therefore, the combination of quantitative analyses with qualitative judgements is advisable. The automobility scores show a good correlation for the OECD countries, thus predictions on VKT saturation for other countries can be made with a certain confidence.

Further research is required with regard to all factors influencing automobility. In particular, the relationship between spatial development, the emergence of new technologies and services and policies warrants more attention.

ACKNOWLEDGMENTS

The study was funded by the Institute of Mobility Research (ifmo) and we express our gratitude to Dr. Peter Phleps for his support and expert input. The preceding study carried out by Ecola et al. (2014) provided the idea and laid the ground for conducting this updated and broadened study. We would like to thank particularly Liisa Ecola, Charlene Rohr and Johanna Zmud for allowing us to build on this earlier work. Furthermore, the study would not have been possible without the engaged contributions from our fourteen country experts to whom we also express our great gratitude . The participating experts were (in alphabetical order): Christian Boettger, A+S consultancy, Saint-Petersburg, Russia; Prof. Dr. Antonio Nelson Rodriquez da Silva, University of São Paulo, São Paulo, Bazil; Vadim Donchenko, researcher at the Transport Ministry, Moscow, Russia; Prof. Pan Haixiao, Tongji University, Shanghai, China; Prof. Lu Huapu, Tsinghua University, Beijing, China; Prof. Johan W. Joubert, Universtiy of Pretoria, Pretoria, South Africa; Prof. Dr. Jeffrey R. Kenworthy, University of Applied Science, Frankfurt Main/Germany, for Australia; Dr. Thomas Meissner, BMW, Munich, Germany; Dr. Marthetha Mokonyama, Council for Industrial and Scientific Research, Pretoria, South Africa; Dr. Luiz Alfonso dos Santos Senna, Federal University of Rio Grande del Sur, Porto Alegre, Brazil; Dr. Senathipathi Velmurugan, Central Road Research Institute, Delhi, India; Prof. Dr. Ashish Verma, Indian Institute of Science, Bangalore, India; Prof. Toshiyuki Yamamoto, Nagoya University, Nagoya, Japan; and Dr. Johanna Zmud, Texas A&M Transportation Institute, Arlington, United States.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Stefan Seum, Tobias Kuhnimhof; data collection: Angelika Schulz, Stefan Seum; analysis and interpretation of results: Stefan Seum, Angelika Schulz, Tobias Kuhnimhof; draft manuscript preparation: Stefan Seum, Angelika Schulz. All authors reviewed the results and approved the final version of the manuscript.

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Appendix

Values of the Gompertz function depicted in **Figure 1**.

	AUS	AUS std.error	GER	GER std.error	JPN	JPN std.error	USA	USA std.error

Υ	9,91E+03	9,32E+01	8,50E+03	1,41E+02	6,00E+03	3,84E+02	1,52E+04	1,79E+02
α	2,04E+01	3,37E+00	7,02E+00	3,96E-01	5,25E+00	3,41E-01	5,93E+00	4,15E-01
β	1,77E-04	8,61E-06	9,58E-05	3,42E-06	7,20E-05	5,69E-06	9,33E-05	3,76E-06