Sułek, M., *Measurement of national power – a powermetric model*,
Przegląd Geopolityczny, 32, 2020, s. 35-57.

Mirosław SUŁEK
Uniwersytet Warszawski

MEASUREMENT OF NATIONAL POWER – A POWERMETRIC MODEL

Abstrakt:

Artykuł prezentuje własny model pomiaru potęgi państw (jednostek politycznych). W odróżnieniu od wielu innych propozycji, ma on charakter dedukcyjny i wysoce syntetyczny. Kolejną jego cechą jest możliwość kalkulacji wielkości pochodnych, opisujących parametry jakościowe mierzonej potęgi. Autor przywołuje też dwa odmienne modele sprzed kilkudziesięciu lat, które miały duże znaczenie w trakcie budowy własnego.

Prezentowany model obejmuje następujące zmienne: zdolność do działań zbiorowych reprezentowana przez Produkt Krajowy Brutto (PKB), liczbę ludności, wielkość terytorium, wydatki wojskowe oraz liczbę żołnierzy w służbie czynnej. Pozwala on szacować trzy rodzaje potęgi: potęgę gospodarczą, potęgę militarną oraz potęgę geopolityczną. Obliczenia te mają na celu identyfikację i ocenę międzynarodowego układu sił – w przeszłości, teraźniejszości oraz w przyszłości. W celach ilustracyjnych zamieszczono wyniki obliczeń wielkości, oferowanych przez model. Całość rozważań mieści się w zakresie potęgometrii – nauki zajmującej się modelowaniem i pomiarami potęgi państw (jednostek politycznych).

Słowa kluczowe: potęga, potęgometria, potęgonomia, potęga gospodarcza, potęga wojskowa, potęga geopolityczna, pomiar potęgi państw, międzynarodowy układ sił.

Introduction

The article contains an extension of the concepts related to the model of measuring the power of states (political units), included in my book "Podstawy potęgonomii i potęgometrii" (*Foundations of Powernomics and Powermetrics*, Kielce 2001). The terminology adopted was since then enhanced. Due to its deductive nature, its genesis will be demonstrated, as well as the logic on which it was based, supplemented with the products of the calculations of quantities enabled by the model (including basic and derived quantities), for illustrative purposes.

All of the considerations fall within the scope of powermetrics – science concerned with modeling and measuring the power of political units.

The power of states (political units), its estimations and measurements have always been an issue of interest for rulers and politicians, yet until the Second World War, they were not very advanced. It was only after the Second World War that this field of study began to thrive. This was prompted by the dynamic development of other scientific disciplines, such as economics, econometrics, game theory, cybernetics and IT. After the Cold War, quantitative studies of the power of states intensified. The simplicity and stability of the bipolar system disappeared, followed by the formation of a new international order, whose main feature was growing instability. This generated new interest in the study of the international balance of power, this time not only on the part of world leaders, politicians and commanders, but also the society at large, which now, thanks to the Internet, is able to keep track of the events on an ongoing basis, and exchange opinions and judgements in real time. Geopolitics was then revived as one of the scientific ways to study international relations.

1. Quantitative studies and measurements in geopolitics, i.e. powermetrics

1.1 About the concept of powermetrics

Powermetrics is the science concerned with the measurement of power of particular players in the international relations, mainly states (political units). The need for such measurements was recognized a fairly long time ago. Since then, various terminology has been proposed. The basic concept of powermetrics is power of the participants in the international relations, mainly states. The changes taking place in the international system, renewed political and military tensions in many regions of the world, and increased rivalry between the changeable number of world powers all result in the terminology of power, force and influence in international relations becoming increasingly common.

A sub-discipline of geopolitics, powermetrics willingly adopts the well-known thesis of Raymond Aron: "the most important feature of any international system is the balance of power", which is why the balance of power constitutes its primary topic of interest. Yet, the "balance of power" consists of many single "powers", which makes them the primary subject of powermetric measurement. Powermetrics also fully adopts the thesis of Bertrand Russell (1996, p. 4): "*The fundamental concept in social science is Power in the same sense in which Energy is the fundamental concept in physics*". This thesis was adopted by the members of the Powermetric Research Network Association (PRNet), who define their mission in the following words: "The PRNet's mission is to develop and promote powermetrics as an applied science. Dealing with the measurement and evaluation of the power of political units, especially nations, and with the use of models and simulations, we can forecast the relations between them on a global, regional and local scale"[1].Powermetrics is an equivalent of econometrics in economic sciences.

It is understandable that the approaches of various researchers to the measurement of political units' power vary – from total approval, scepticism, to full rejection. One example of the latter approach is constructivist Stefano Guzzini from the Danish Institute for International Studies (DIIS). He states that the concept of power is central to international relations theories – it serves to explain the notion of the "balance of power", or to predict the outcome of a potential conflict when the distributions of power are known. "Such power analysis must assume the measurability of power. Unfortunately, such measures are of no avail, not because we have not yet thought enough about it, but because it is not possible"[2]. I reject Guzzini's view as unwarranted. Generally, I agree with the idea that almost anything is measurable(Hubbard, 2013, p.9, 17).The measurement occurs on several scales (levels), which, simply put, can be described as moving towards increased accuracy. It is the author's opinion that the lack of this awareness may be the reason for many unnecessary discussions.

Every measurement primarily serves practical purposes. Cognitive considerations are also of vital importance. One of the underlying motives for measuring and assessing the international system in terms of power relations is the hope that the spread of objectified methods of measurement will contribute to more peaceful resolutions of many international conflicts. In any case, one cannot be discouraged by failure.

It goes without saying that errors in estimations, calculations and measurements are unavoidable. Even in physics – science which, when it comes to precision, has almost reached perfection in some of its disciplines compared to the social sciences – the accuracy of measurement varies widely. In addition, errors should be considered against the purposes for which the estimates are to be applied; in some cases, the acceptable error margins may be wide (Kuznets, 1976, p. 15).

1.2 Terminology – early proposals

Garry King, promoting the development of quantitative methods of political analysis, proposes several terms describing a quantitative approach to political science, such as: *Politimetrics* (Gurr, 1972), *Polimetrics* (Alker, Jr., 1975; Osabu-Kle, 1997), *Politometrics* (Hilton, 1976; Frey 1979; Turnovec, 2003;

[1] Mission of Powermetric Research Network, http://prnet.org.pl/en [access: 27.04.2019]
[2] S. Guzzini, On the measure of power and the power of measure in International Relations, DIIS Working Paper 2009: 28, p. 4 - https://www.ciaonet.org/attachments/15295/uploads [access: 28.10.2019].

Colomer, 2017), *Political Arithmetics* (Petty, 1971), *Quantitative Political Science* (*QPS*), *Governmetrics*, *Posopolitics* (Papayanopoulos, ed., 1973), *Political Science Statistics* (Ray, Blydenburth, 1973), *Political Statistics* (Rice 1926). He then writes that if political methodology is to play a major role in future political science, scholars will need to expand quantitative analyses. This does not mean that they need to build increasingly complex statistical models. Instead, we need to reflect more of the essence of political phenomena in our models (King, 1991).

Add to this the Kenneth Boulding's proposal – *Politicometrics* (Rashevsky, Trucco, 1960). This term was probably most frequently mentioned. It was also adopted by Dr Stephen D. Slingsby, director of the Politicometrics Research Program at the Ohio State University. On its elementary level, *politicometrics* was understood as the science of measuring political behaviour. In terms of scope and application, it could be divided – at the level of didactics and research – into four categories: micro and macro; basic and applied (Friend, ed., 1969, p. 81-82). The current prevailing meaning of the term *politicometrics* is shifting towards the study of political systems with the use of quantitative methods. This area of research is explored e.g. at Meiji Gakuin University[3]. In 2014, Kyung Hee University implemented the national programme *Creative Korea-II (CK-II)*, including 13 subjects within the "Global Civil Society" category, of which at least 4 had to be selected; students had the option of choosing *Politicometrics*[4].

Apparently, the above mentioned terms referred to the term *politics*, of which, it seems, only *politometrics* and *politico metrics* remained. At the same time, terms referring to *power* emerged - first *powernomics*, and later – *powermetrics*, already briefly discussed.

1.3 Development of terminology – powernomics and powermetrics

The term *powernomics* appears for the first time in the title of the book "*Powernomics. Economics and Strategy After the Cold War*" edited by C.V. Prestovitz, R.A. Morse, and A. Tonelson (1991).As the editors of the book explain: *The title, Powernomics, is meant to highlight the tight link between economics and other aspects of national welfare. It was conceived in order to define an American response to the end of the Cold War to the dawn of a new era in which national security will increasingly be defined in economic terms, and in which the United States will face unprecedented challenges without the benefit of past superiority in industry, technology, and finance*" (Ibid., p. ix). As the events on the international area show, this thesis turned out to be too optimistic.

The editors set clear goals for the work. *Powernomics has three main purposes. First, it presents in a helpful way basic works that explain to readers how national and global*

[3] Daily summary of Japanese press, American Embassy, Tokyo, web.stanford.edu/dept/SUL/wwwsul/test/.../SM000811.doc [access: 18.03.2018].

[4] Kyung Hee University for Creative Korea-II (CK-II), http://kic.khu.ac.kr/home/wp-content/uploads/2015/02/4x4_overview.pdf [access: 18.03.2018].

developments are affecting America's well-being – and their own. Second, its sections are arranged to guide readers through a thought process that reveals the magnitude of the challenges confronting us, and explains why the conventional wisdom has been so slow to recognize them – and, in fact, continues to deny that they exist. Third, the volume spotlights the questions that need to be asked in order to meet these challenges (Ibid., p. x).

Although the book highlights the importance of the economic factors, the other components of the state power are not forgotten: *Economics and international power relationships are part and parcel of each other. Military power, political power, and economic power are all mutually reinforcing. And when any one of these varieties of power is in short supply, the others will be diminished* (Ibid., p. xii-xiii).

The term *powermetrics* is derived from *powernomics* and, in short, is a quantitative development of *powernomics*. Therefore, we end up with a conceptual cluster *powernomics – powermetrics*, as it is in economic sciences: economics – econometrics. Both powermetrics and econometrics are mainly based on modelling.

1.4 Powermetric vs econometric models

The approach to modeling in powermetrics and in econometrics is similar in formal terms, yet it differs in methodological terms. The reason for this is the separateness of powernomics from economics. This is illustrated by the following comparison:

1. The most common approach in economics and econometrics is the micro approach; in powernomics and powermetrics, the macro approach.
2. In economics and econometrics, greater accuracy is possible and is required. Due to various market signals, mainly in the form of prices, a precise input and outcome calculation is possible, desirable and expected, as it determines a company's survival on the market. Powernomics and powermetrics do not use such accurate information; here, precise measures of power are not so important, which is why the powermetric models have so far been much simpler than the econometric models. In the science of international relations or in geopolitics, the level of precision which is possible in economics is not required.
3. Economics and econometrics are concerned with human activity in the positive-sum game system, whereas powernomics and powermetrics are focused on human activity in the zero-sum game system. A positive-sum game means that all of the parties involved benefit from it (the parties' interests match), while in a zero-sum game, one party benefits at the expense of others (conflict of interest). Struggles for power are a zero-sum game.

4. Powernomics is focused on power relations (gross, total), while economics is focused on net worth and economic surplus.

In economics and econometrics, expressions of inputs and outcomes are fairly accurate. In powernomics and powermetrics, the results can be quite different. It is unclear what should be considered as inputs, and what to count as outcomes, which is a problem that also applies to economics and econometrics.

Considering that "geopolitics is the art and practice of using national (political) power over a given territory", and bearing in mind the striving towards maximizing power in a competitive environment, we may assume the increases/decreases in the power of states in particular ranges of time as inputs and outcomes. For this, the synthesis of different measures of power is required, as provided by powermetrics.

2. Key models

Interest in power relations, both in the military and in geopolitical terms, is ages old. It always attracted rulers and commanders, but it was not until after the Second World War that an increased interest arose in estimating and measuring the power of states. This was facilitated by an unprecedented development of information technologies and the progress in formal sciences, such as cybernetics, game theory, econometrics etc.

Some models are shortly presented below, which go beyond the current and contextual considerations, and which are crucial for my model. A broad review of the proposed models and approaches is made in my book "The Power of Nations. Models and Applications" (Sułek, 2013). Karl Höhn (2011) expanded on it even more widely in his doctoral dissertation "Geopolitics and the Measurement of National Power".

W. Fucks's model

Wilhelm Fucks (1892-1990) was a physicist who was interested in the dynamics of a variety of systems, including those not related to physics. In this respect, he was primarily concerned with the changes in the international balance of power, including long-term forecasts of the future international balance of power (Fucks, 1965; 1978). He developed a model based on the so-called three power-generating factors, namely steel production, energy production, and population. After numerous simulation analyses, Fucks proposed the following power formulas:

$$M = \frac{M_s + M_e}{2} ,$$

wherein:

$$M_s = S \times L^{\frac{1}{3}},$$

$$M_e = E \times L^{\frac{1}{3}},$$

where:
M – synthetic indicator of the power of states (M – from the German *Macht*, which stands for Power)
Ms – partial indicator based on steel production and population
Me – partial indicator based on energy production and population
S – steel production
L – population size
E – energy production

Currently, the model appears obsolete, however, up until the late 1960's, it was considered reliable. The choice of these particular power-generating factors was justified mainly by the fact that most of the countries in the world – not only communist countries– did not have market economies. This made the comparisons in terms of value (GDP and other) very difficult. The adopted steel production and energy production variables are a substitute for value measures. It is noteworthy that Fucks's model does not refer directly to any military measures, therefore it appears more suitable for long-term analyses rather than those that are currently available. In addition, the ratio of exponents is 3:1 in favour of steel and energy, which suggests that after the contribution of the steel/energy factor, the final result is three times greater than the size of the population. Hence, in order to compensate for the deficiencies in steel/energy production, a significant advantage in the population size is required.

R. Cline's model

Ray Steiner Cline (1918-1996) first presented his model in a book published in 1975[5]. His formula is illustrated as follows:

$$P_p = (C + E + M) \times (S + W),$$

where:
P_p – perceived power
C – critical mass – population and territory

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[5] This is not the only presentation of this model. In 1977, an extended and revised edition of his book was published (Cline, 1977). It was also presented in his later book, which includes assessments of the power of selected countries from the early nineties (Cline 1994).

E – economic capability
M – military capability
S – strategic purpose
W – will to pursue national strategy

In order to operationalize the model, or to express it in numbers, Cline proposes point assessments made by experts. For example, the variable C, or population size and territory, can each be given a maximum of 100 points, i.e. a total of 200 points. Strategy and will – from 0 to 1, respectively, i.e. a minimum of 0 points (0 + 0 = 0), and a maximum of 2 points (1 + 1 = 2).

Considering the purpose of this article, it is essential to look at the variables which together form a whole. These include the "material" variables (population, area, economy and army) and the "spiritual" variables (strategic purpose and will). So we have the following factors: demographic and spatial, economic, military, political and volitional (moral).

3. Proposal of new model

3.1 Basic model

While constructing the model, I decided that it should be grounded on the necessary number of CONSTANT FACTORS in history, which are inherently connected with the existence and functioning of political units. I considered the following factors: PEOPLE acting in a given AREA at a given TIME, possessing specific ORGANIZATION AND PRODUCTION SKILLS, or the capacity for collective action, and thus for social processing of matter, energy and information. As people perform ACTIONS, these render specific RESULTS. From the perspective of a political unit, GDP (Gross Domestic Product) can be considered a valid synthesized RESULT. Other possible measures may also be considered, such as GNP (Gross National Product), yet these are not relevant at this stage of consideration. Thus, the variables we will look at include: *people*, *area*, *time* and *results* of collective actions.

Each political unit is suspended between peace and war. For this reason, some people engage in production-service activity oriented towards the time of peace, while some other people are more focused on war time. The external expression of people's organization and production capacity is the *product value* – *value* which is an expression of the social assessment of a given product or service, abstract in nature, and thus of an *information-energetic* character, even though it is expressed by means of material products. The current value of products is estimated in time, and therefore has a flow nature. Considering the above features, the power of political units can be represented as a function:

$$P = f\left(\frac{Q}{T}; L; a\right). \qquad (1)$$

where:
P – political unit's power
f – function
Q – product value
T – time
$\frac{Q}{T}$ – value flow processed by a political unit
L – population size
a – territory of a given political unit

The basic value determinant of a political unit is its GDP, which is a flow, as it is a value produced in a given territory within a unit of time. As GDP, population, territory and time are all economic variables, the function connecting them reflects *economic power*, which can also be considered *overall power*. It can be illustrated as below:

$$P_e = f\left(\frac{GDP}{T}; L; a\right). \qquad (2)$$

where:
P_e – economic power
GDP – Gross Domestic Product
$\frac{GDP}{T}$ – GDP expressed as a flow

Almost each political unit devotes part of its GDP to meeting the needs of external security, in the form of military or defense expenditures etc.
The military power is thus a function:

$$P_m = f\left(\frac{ME}{T}; S; a\right). \qquad (3)$$

where:
P_m – military power
ME – military expenditure
$\frac{ME}{T}$ – military expenditure expressed as a flow
S – number of active-duty soldiers

If *m* stands for the share of military expenditure in GDP ($m = ME/GDP$) and *s* denotes the share of the number of active-duty soldiers within the entire population size ($s = S/L$) we end up with two measures of militarization – economic and demographic. As m $\in$ [0, 1], therefore:

$$P_m = f\left(\frac{m \times GDP}{T}; s \times L; a\right). \qquad (4)$$

The above formula enables the calculation of the economic power of political units, when *m* = 1 (for the entire GDP) and *s* = 1 (for the total population size). By substituting the actual share of military expenditure in GDP (*m*) in the formula and the actual share of the number of active duty soldiers in the statistical population (*s*), we will obtain a measure of military power. Then, for simulation purposes, we may want to adjust any rates of *m* or *s*.

To summarize:

1) Gross Domestic Product represents the *economic* factor;
2) Military expenditure represents the *military* factor;
3) The rate of military expenditure *m* and the share of soldiers in the population *s* represent the *strategic* factor (recognition of the role of the military factor) and the *volitional* factor (the will to implement governmental policy) – while the strategic factor is *intellectual* in nature, the nature of the *volitional* factor is *ethical* and *aesthetic*;
4) Population represents the *demographic* factor (population still underlies GDP and the armed forces);
5) The *geographical* factor is represented by the area of a given political unit.

Due to the use of the above factors in my model, it may be treated as an operationalization of R. Cline's model. The operationalization proposed by Cline himself, in the form of assigning a certain number of points to particular variables, is not satisfactory due to its inherent subjectivity.

Assuming that the model for calculating the power of states is a production function, we obtain:

$$P_e = \left(\frac{GDP}{T}\right)^{\alpha} \times L^{\beta} \times a^{\gamma}; \qquad (5)$$

$$P_m = \left(\frac{ME}{T}\right)^{\alpha} \times S^{\beta} \times a^{\gamma}; \qquad (6)$$

α ,β, γ – structural positive function parameters, or power flexibility coefficients. For the economic power, these include coefficients related to Gross Domestic Product (GDP), population size (L) and area of territory (a);

for the military power – to military expenditure (ME), number of active duty soldiers (S) and area of territory (a).

A substantive analysis shows that the amount of power is determined first and foremost by GDP, then the population size, and finally the territory. Therefore $\alpha > \beta > \gamma$. However, there is still little information on the proportions between these parameters.

From a formal point of view, $\alpha + \beta + \gamma$ may equal 1, less than 1 or greater than 1. If $\alpha + \beta + \gamma > 1$ – the result is increasing revenues; if $\alpha + \beta + \gamma < 1$ – decreasing revenues; and fixed revenues when $\alpha + \beta + \gamma = 1$. In other words, with increasing revenues, an increase of each variable by 1% results in an increase of the result (power) by more than 1%; with decreasing revenues, an increase of each variable by 1% results in an increase of the result (power) by less than 1%; with fixed revenues, an increase of each variable by 1% results in an increase of the result by 1%.

In the model under consideration, according to the law of diminishing marginal utility, the sum of exponents should be less than 1, so $\alpha + \beta + \gamma < 1$. However, it is still not known how much less it should be, and what the individual exponents α, β, γ are.

There are, however, some premises to define the ratio $\frac{\alpha}{\beta}$. In a letter to his brother Joseph, Napoleon wrote: "The moral is to the physical as three is to one"[6]. In Wilhelm Fucks's model, the ratio of exponents relating to steel and energy to the exponent related to the population is 3 to 1. This proportion is supported by empirical evidence.

The exponent γ stands between 0 and β. It can be assumed then that $\gamma = \frac{\beta}{2}$. This was assumed in the early version of the model of 1990, which was the basis for further analyses. The applied formula was as follows:

$$P = e^{\log(GDP^{1.5} x L^{0.5} x a^{0.25})} \qquad (7)$$

or, once transformed:

$$P = GDP^{0{,}65144} \times L^{0{,}21715} \times a^{0{,}10857}. \qquad (8)$$

[6] *International Military and Defense Encyclopedia*, 1993, p. 555. I consider Napoleon's statement as precise rather than estimated.

The assumed exponents are in line with the proportions (3:1:0.5), while in (8) their sum is less than 1, yet it is still not known whether it is fully justified. The following may be noteworthy:

$$\frac{e^{log2,25}}{ln10} \approx 0,618.$$

As can clearly be seen, the number 2.25 is the sum of power exponents in the exponential-logarithmic function P (6). The numbers 0.618 (and its inverse 1.618) are connected with the so-called Fibonacci sequence and the golden ratio. The connection between (6) and the golden ratio does not seem to be accidental. After all, our mathematical models are often based on the proportions inspired by nature.

However, in order to match the golden ratio more precisely, the model needs to be tightened somewhat. In the exponential-logarithmic form (6), the exponents should then be:
α = 1,502205548,
β = 0,500735183,
γ = 0,250367591.

In the power form (7):
α = 0,65239958,
β = 0,21746653,
γ = 0,10873326.

Consider that the sum of power exponents in (7) is: $\alpha + \beta + \gamma =$ 2.253308322, and in (8): $\alpha + \beta + \gamma = 0.97859937$.

Assuming the above adjustments and rounding the exponents to the third decimal place, we finally get:

$$P_e = \left(\frac{GDP}{T}\right)^{0,652} \times L^{0,217} \times a^{0,109} ; \qquad (9)$$

$$P_m = \left(\frac{ME}{T}\right)^{0,652} \times S^{0,217} \times a^{0,109} . \qquad (10)$$

The presence of time (T) in the w above formulas demonstrates that we are dealing withflows, i.e. the flows of value in time. As a rule, in the formal notation of the formula, time is omitted – it remains implied, and then formulas (9) and (10) take the following form:

$$P_e = (GDP)^{0,652} \times L^{0,217} \times a^{0,109}; \quad (11)$$

$$P_m = (ME)^{0,652} \times S^{0,217} \times a^{0,109}. \quad (12)$$

Having defined P_e and P_m, we can also express *geopolitical power* (P_g). It is based on two pillars: geopolitical and military. In other words, it is the result of economic and military power. Significantly more important than the economic power, the military power is assumed to be twice as large as the economic power. Thus, P_g is expressed by the following formula:

$$P_g = \frac{P_e + 2 \times P_m}{3}, \quad (13)$$

where:
P_g – geopolitical power

The above models include all of the variables mentioned – population (L), capacity for collective action (GDP), area (a) and time (T) – for economic power, and active duty soldiers (S), capacity for military action (W), area (a) and times (T) – for military power. It is noteworthy that while the population size is a quantitative indicator, the GDP (more precisely, GDP per capita) is a qualitative indicator of human resources.

It must be added that the military power formula fails to directly include nuclear weapons – a crucial factor in international politics. It is included indirectly in military expenditure, yet the presented model may be subject to simulation and extension. The results of the application of any model are only a starting point for expert assessments. For instance, in the case of economic power, "qualitative indicators" may precede each variable. One example is area – one area will differ from another; there are terrain differences, climate differences, varying natural resources, etc. The same applies to population – population density, spatial distribution, or GDP – each being varying structures of the factors that create it. In the case of military power, the model can include the number of reserve forces, the structure of the defence budget broken down into current spending, spending on weapons and armaments, and research and development. For the sole purpose of learning about the basic features of the international balance of power and the direction of its changes, the "refinements" mentioned above are not necessary. They can be downright confusing, therefore it is advisable to be careful and reasonable when applying them.

The adoption of GDP as a reflection of the capacity for collective action has been widely criticized for several decades, yet it is still difficult to replace it with another indicator. For the time being, GDP is going to be used, which does not preclude the possibility of replacing it if a more reliable indicator is discovered in the near future. Importantly, it should reflect people's capacity for organized action for the benefit of society as a whole. The same applies to military expenditure, whose share in the aggregate indicator of capacity for collective action will remain a measure of society's defense (military) effort.

To sum up, the above models reflect the power of the state (political unit) in the form of energy flux i.e. power. If we apply the language of cybernetics, we can say that power features the state (political unit) as an autonomous system with a given capacity to process energy in time. In other words, the power of a political unit is expressed by its ability to process objectified social energy in a unit of time, i.e. socially accepted in international and internal relations. Therefore, it is a kind of social, or sociological, force. Thus, the following definition of the power of the state can be assumed, expressed in terms of force:

The power of the state expressed in terms of power (in a physical sense) is the amount of social (sociological) energy processed in a unit of time.

Expressing the power of states with a force dimension is the fundamental method of describing the international system in terms of power relations.

The presented model also enables the measurement of the power of states in terms of potential energy (their potential). This would, however, require the introduction of the notion of wealth to the model (in place of GDP or military expenditure), which is, in our opinion, in itself complicated and ambiguous. Nevertheless, its definition would be as follows:

The power of the state expressed in terms of potential energy (its potential) is the accumulated amount of social (sociological) energy for a given moment of time.

Reasoning in terms of resources and fluxes comes naturally if two commonly used categories are considered: wealth and income. Wealth is a resource which may, for example, amount to $ 1 million as of December 31, 2019, while income is a stream/flux (e.g. $ 5,000 per month), i.e. it expresses the amount of money flowing at a given time in a given area, covering a given number of citizens covering a given population.

3.2 Derivative quantities

The model also allows for the calculation of derived values. The following indicators are included: militarization, productivity and power density.

Militarization (m)

Three separate indicators of militarization can be distinguished, all being dimensionless quantities. The first one relates to economic militarization P (m_e)– it expresses the ratio of military power to economic power, therefore:

$$m_e = \frac{P_m}{P_e}.$$

It may as well be interpreted as an *indicator of mobilization*, as it shows how much of the resources were allocated (mobilized) for military (defense) purposes, as well as an indicator of *defense readiness*.
The other two indicators refer to partial (sectoral) militarization. The first one expresses the militarization of GDP (m_{GDP}):

$$m_{GDP} = \frac{MEX^{0,652}}{GDP^{0,652}}.$$

The second one indicates demographic militarization (m_L):

$$m_L = \frac{S^{0,217}}{L^{0,217}}.$$

All three indicators describe the type of defense (military) policy pursued by the state. Three standard situations can occur here. First, when the state clearly has a higher position in terms of GDP militarization than in terms of demographic militarization. Second, when the opposite occurs, i.e. demographic militarization clearly exceeds GDP militarization. And third, when both of these indicators remain in approximate balance.

Economic productivity (p_e)

The economic productivity indicator is expressed by the following formula:

$$p_e = \frac{(GDP)^{0,652}}{L^{0,217} \times a^{0,217}}$$

This indicator can be interpreted as a general measure of the society's organization in time and space, or as a measure of broadly understood performance, as it combines economic, demographic and space-time factors. Undoubtedly, it is one of the forms of social efficiency.

Military productivity (p_m)

The military (defense) indicator is a product of economic productivity and militarization indicator.

$$p_m = p_e \times m,$$

$$p_m = \frac{(ME)^{0,652} S^{0,217}}{L^{0,434} \times a^{0,217}}$$

The military (defense) productivity indicator expresses the level of military (defense) readiness of society, determined mainly by the level of economic development and militarization, as well as the degree of consolidation of power factors in time and space.

Similarly to the productivity indicators, there are two indicators of power density.

Density of economic power (d_e)

The indicator of the density of economic power is described by the following formula:

$$d_e = \frac{(GDP)^{0,652} \times L^{0,217}}{a^{0,217}}.$$

This indicator reflects the level of economic and demographic saturation of the time-space factor. In other words, it combines data regarding the level of economic development and population density.

Density of military power (d_m)

The military power density indicator is the product of the economic power density and the militarization factor.

$$d_m = d_o \times m ,$$

so:

$$d_m = \frac{(ME)^{0,652} \times S^{0,217}}{a^{0,217}}.$$

Similarly, this indicator reflects economic-military and demographic-military saturation of the space-time factor. It is of great importance in defense analyses – the higher it is, the more difficult it will be for an opponent to "penetrate" through it. It can therefore be interpreted as an indicator of potential resistance for an advancing army.

Calculation

In general, there are two methods used in the process of determining calculations. The first and recommended method involves converting statistical data into global shares, which we then use in the formula. The resulting power indicators will refer to the entire world, and therefore will be tractions of the global power.

On a global scale, the Gross Global Product (GGP) indicator should be of interest to us, understood as the sum of GDP of all states and dependent territories, similarly to the population size and the area of territory (which should not be considered as the area of the entire globe!). In short, the sum of all the variables should make up a whole. Certainly, some deviations are unavoidable, yet they will not significantly affect the results, especially those related to the population and area (due to the relatively low exponent).

As for GDP, there are two main methods of converting national currencies into a common currency. Most often, it is the US dollar at the exchange rate, or expressed according to purchasing parity standards (PPP – Purchasing Power Parity). Bearing in mind the study of international power relations, the exchange rate is preferred. However, in order to broaden one's basis of understanding, it would be worthwhile to use both methods.

The other method (not recommended but sometimes necessary) is used when no data is available for any of the variables in relation to the whole world. If this is the case, direct data is substituted in the formulas. For example, GDP (military expenditure) in USD; population – in number of individuals; area – in thousands of km^2. In this case, some point of reference must be established(a country or a group of countries) and considered as 1, 100, 1000. It should be noted that this method is applicable only for the calculation of the power relations within a particular group of countries, without the crucial insight into the question of what part of the world-power is represented by the power calculated for the group of countries under consideration. This method was adopted, for example, by Wilhelm Fucks,who considered the US as a benchmark, with an assigned value of 1000.

Assuming that the power of the world is a reference point for individual states, it should be regarded as a whole equal to 1. As a result, the power of individual states is a fraction (share) of the power of the world. In the case of smaller countries, it is convenient to multiply their shares by 100, 1000, or even a million. If the power of the world equals 1 Mir (1M)[7], then the power of the states can be expressed as a percentage of the power of the world, or in millimirs (mM), as thousandths of the power of the world.

This is illustrated in the table below, which includes the basic available data (for 2015), necessary for the calculation of the economic power of the states.

Tab. 1: Basic data for the calculation of economic power of states (2015)

	Absolute quantities			Relative quantities		
	GDP	L	a	GDP	L	a
	mld $	mln	tys. km^2	-	-	-
WORLD	73433,6	7349,3	134325,3	1	1	1
USA	17947,0	321,8	9831,5	0,244398	0,043782	0,07319
China	10866,4	1376,0	9562,9	0,147976	0,187231	0,07119
Poland	474,8	38,6	312,7	0,006465	0,005254	0,00233

Source: author's own calculations.

According to the proposed model, the economic power of the United States will be as follows:

$$P_{o\,USA} = ([0{,}244398])^{0.652} \times ([0{,}043782])^{0.217} \times ([0{,}07319])^{0.109} = \mathbf{0{,}152204.}$$

If we multiply the calculation result by 100, the result in percentage will be as follows:

$$0{,}152204 \times 100 = 15{,}204\%.$$

If we multiply the result by 1000, we obtain the result in millimirs:

$$0{,}152204 \times 1000 = 152{,}204\ \mathbf{mM}.$$

Finally: the economic power of the United States constitutes 0.1522014 of the world power, or 15,2014%, equal to 152,204 millimirs (mM).

The economic power of Poland:

$$P_{o\,POL} = ([0{,}006465])^{0.652} \times ([0{,}005254])^{0.217} \times ([0{,}00233])^{0.109} = \mathbf{0{,}06178}$$

etc.

[7]In Russian, *Mir* stands for *world*.

Examples of calculations for all three types of power, i.e.P_e, P_m and $P_g$are included in Table 2. The results of calculations of derivative quantities are included in Table 3.

Tab. 2: Economic, military and geopolitical power for the first 15 states in each category (2018; in mM, the world = 1000; GDP – according to currency exchange rates)

	Economic power		**Military power**		**Geopolitical power**	
	Country	mM	Country	mM	Country	mM
1	China	156,80	USA	226,18	USA	200,50
2	USA	149,13	China	103,26	China	121,10
3	India	48,19	India	42,18	India	44,18
4	Japan	33,91	Russia	39,10	Russia	34,68
5	Brazil	28,13	Saudi Arabia	34,45	Saudi Arabia	26,05
6	Germany	26,72	France	21,75	Japan	24,66
7	Russia	25,82	Brazil	21,39	Brazil	23,63
8	France	21,13	Japan	20,04	France	21,55
9	UK	19,51	UK	19,18	Germany	21,05
10	Canada	18,39	South Korea	18,80	UK	19,29
11	Indonesia	17,16	Germany	18,22	South Korea	16,41
12	Mexico	16,31	Iran	15,64	Australia	14,27
13	Italy	15,96	Australia	14,01	Canada	13,81
14	Australia	14,77	Italy	11,89	Italy	13,25
15	Spain	12,53	Canada	11,52	Indonesia	10,94

Source: author's own work on the basis of the World Bank data (GDP) and the UN database (population size and area).

In terms of economic power in 2018, China ranked first, having surpassed the United States for the first time in 2017. In other categories, China still remains far behind. Considering the balance of power in terms of polarity, it is clearly seen that a bipolar system (China – USA) has emerged on the basis of economic power, a unipolar system (USA) on the basis of military power, and a weak bipolar system on the basis of geopolitical power (the advantage of the USA over China is less than double).

Analysis of the data contained in Table 3 provides many interesting insights. For example, the USA and China: despite the proximity in terms of economic power, the United States has a considerable advantage in nearly all qualitative indicators (except for economic density). This is due to their high level of economic and demographic militarization, as is the case with Russia. It should be noted that Japan and Germany are demilitarized countries with high rates of economic productivity. By comparison,India, a country placed high in the power rankings (due to its significant population size), has considerably low qualitative indicators. The low level of some indicators, e.g. economic productivity, or especially economic density, is largely due to vast territory (Russia, Canada, Australia).

Tab. 3: Derivative quantities for the first 15 countries ordered according to their economic power (2018; world average = 1)

	Political units	Militarization			Productivity		Density	
		m_e	m_{GDP}	m_L	p_e	p_m	d_e	d_m
1	China	0,659	0,745	0,884	0,766	0,504	0,367	0,242
2	USA	1,517	1,368	1.109	1,378	2,089	0,352	0,534
3	India	0,875	1,060	0,826	0,347	0,304	0,164	0,144
4	Japan	0,591	0,628	0,941	1,353	0,799	0,229	0,135
5	Brazil	0,760	0,844	0,902	0,325	0,247	0,068	0,052
6	Germany	0,682	0,708	0,963	1,298	0,885	0,183	0,125
7	Russia	1,514	1,250	1,211	0,281	0,426	0,050	0,076
8	France	1,030	0,993	1,037	0,973	1,002	0,125	0,129
9	UK	0,983	1,015	0,969	1,176	1,156	0,150	0,148
10	Canada	0,627	0,677	0,926	0,438	0,274	0,043	0,027
11	Indonesia	0,457	0,515	0,886	0,293	0,134	0,069	0,031
12	Mexico	0,360	0,373	0,966	0,377	0,136	0,064	0,023
13	Italy	0,745	0,730	1,020	0,941	0,701	0,115	0,086
14	Australia	0,948	0,970	0,977	0,441	0,418	0,037	0,035
15	Spain	0,673	0,674	0,999	0,695	0,468	0,076	0,051

Source: author's own calculations

Conclusion

The proposed model was created on the basis of axiomatic-deductive rather than empirical-inductive reasoning. It is, therefore, highly synthesized, yet it appears to withstand empirical testing. I believe that it can perform as the basis of theidentification and assessment of the international balance of power in the short, and most especially, in the long term.

Each formula, model or assessment may be downgraded as being subjective, lacking crucial assessment parameters, or containing inadequate weight distribution of the factors considered etc. In order to minimize such shortcomings, objectivity should be applied in the course of both performing the procedures and analyzing results.It is essential that *expert assessments* include not only theoreticians, but also practitioners, especially those whose decisions reflect some grasp of an international balance of power. This primarily concerns politicians, diplomats and senior military personnel. Expert assessments may also serve to properly select the features (parameters) necessary for determining the weights of individual variables or establishing the "correct" (model) classification of the states according to their power. Ultimately, these opinions may and should be used to evaluate the final results.

To limit the shortcomings of the proposed model, it is imperative to apply proven statistical methods. These enable data organization and comparison of results obtained using various methods. In addition, a model distribution of countries, as arranged by experts, can be applied in order to search for the regression function, which is used as the basis for forecasting. Another factor contributing to minimizing errors is simulation studies, which enable the traceability of the results obtained using various combinations of models, variables and their impacts.

Modeling and measuring the power of states in order to identify and evaluate the international balance of power is a complex task. However, further work is needed to obtain even more accurate results, which would serve as a foundation for better decision-making by global powers in the future. There is a reasonable hope that a good understanding of the international balance of power could contribute to more peaceful resolutions of international disputes and conflicts. From this point of view, the advantages of simulation should be emphasized as a method of forecasting the results of future conflicts in the international arena.

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Sułek, M., *Measurement of national power – a powermetric model*,
Przegląd Geopolityczny, 32, 2020, s. 35-57.

Measurement of national power – a powermetric model

This article presents the author's own model for measuring the power of states(political units). Unlike many other proposals, it is deductive and highly synthesized. It also enables the calculation of the quantities of the derivatives referring to the quality parameters of the power under measurement. The author also refers to two different models first introduced several dozen years ago, which were of great importance to creating his own. The presented model includes the following variables: the capacity for collective action represented by Gross Domestic Product (GDP), population, size of territory, military expenditure, and the number of active-duty soldiers. It enables the estimation of three types of power: economic, military, and geopolitical. The resulting calculations are designed to identify and assess the international balance of power – past, present and future. For illustrative purposes, the products of these quantity calculations are presented within this article. All of the considerations fall within the scope of powermetrics, which is the science concerned with modeling and measuring the power of states (political units).

Key words: power, powermetrics, powernomics, economic power, military power, geopolitical power, measurement of national power, international distribution of power.