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MODELLING AIR CARGO MARKET – A GRAVITY METHOD

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Abstract

The gravity method and its expansions in transport economics, analogical to Newton's gravity law are not the most modern approach to demand estimation. They are, however, simple and applicable to the publicly available data as those of EUROSTAT or national statistics sources. Main assumption is that the trips (or in this case flows of cargo) are produced at an origin and "attracted" to destination according to some identifiable pattern. It is possible to suggest – but not ensure as in Newton's Physics – these patterns, provided a complete list of socioeconomic data (GDP, population, ...) or other quantifiable conditions in the range (catchment) of all locations (nodes), combined with a series of corresponding flow volumes using a non-linear equation. Each variable of the explanatory side of the equation is equipped with a weight (in econometrics called a parameter). Due to non-linear form of the equation parameters are found using an Iterative calculation that is typically performed by the Maximum Likelihood Estimation (popularized by Ronald Fisher). Validity of calculations are checked using statistical measures of proportionate reduction in uncertainty.

Keywords: air transport, gravity model, maximum likelihood estimation.

1. GRAVITY MODEL - INTRODUCTION

For the purpose of demand analysis, the transport systems theory suggests, among other methods, using an aggregate function representing group behaviour. [1)]

$$V = D(A, S) \qquad \text{(Eq. 1)}$$

where V is the vector of volumes or numbers of consumers making particular choices, A represents the social, economic and other characteristic of the activity system and of the individuals in the group and S the service attributes that characterize the transportation choices open to prospective travellers.

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1) Manheim, L. M. (1979), p. 116.

2. EXPANSION OF THE GRAVITY MODEL

The theory considers expansion of the generalized demand function into the **gravity I** model:

$$V_{kd} = Y_k * Z_d * L_{kd} \qquad \text{(Eq. 2)}$$

where Y_k is some measure of the intensity of activity at zone k, such as the population, Z_d is some measure of the intensity of activity at zone d, such as the population or employment level and L_{kd} represents the effect of transportation service attributes on demand for travel between k and d.

3. APPLICATION OF THE MODEL AND DATA[2)]

All standard gravity I explanatory variables[3)] (i.e. Y, Z, L or in particular: GDP_i, GDP_j, $population_i$, $population_j$ aggregated in airport catchment areas[4)] ordered as a 4 x n matrix **X**) were formulated in a product function with a vector of parameters (**β**):

$$\boldsymbol{V} = \alpha \boldsymbol{X}^{\boldsymbol{\beta}} \qquad \text{(Eq. 3)}$$

Then, to increase model **advisory efficiency** and numerical fit, extra explanatory variables were included.

Extra variables	**explanation**	**Source**
DTO or **DTD**	"General government gross debt " at origin (or destination)	IMF
CTO	"Domestic credit to private sector (% of GDP) at origin"	WB
IDOC	"number of the required import documents" All documents required per shipment to import goods are recorded. It is assumed that the contract has already been agreed upon and signed by both parties. Documents required for clearance by government ministries, customs authorities, port and container terminal authorities, health and technical control agencies and banks are taken into account. Since payment is by letter of credit, all documents required by banks for the issuance or securing of a letter of credit are also taken into account. Documents that are renewed annually and that do not require renewal per shipment (for example, an annual tax clearance certificate) are not included.	WB

2) Bolded letters in equations mean vector notation.

3) EUROSTAT (nama_r_e3gdp, demo_r_gind3) and WORLD BANK (NY.GDP.MKTP.CD, SP.POP.TOTL), 2013-03-25

4) with accessibility improvement factor, see AIRPORT CATCHMENT in Appendix

$\boldsymbol{TTM} = \frac{\lvert Time_{\,i} - Time_{\,j}\rvert}{100}$	"business environment compatibility" time to prepare and pay taxes in days	WB
$\boldsymbol{INF} = \frac{\lvert GDPdeflator_i - GDPdeflator_j\rvert}{100}$	"economies distance" inflation measuring economy type	WB
$\boldsymbol{TRF} = simple\ avg.tariff$	"trade barrier" Simple average tariff applied by destination sovereign.	WB

In order to avoid the so called "zero gravity" problem[5], the above variables were incorporated to the model in an exponential form.

$$\boldsymbol{V} = \alpha \boldsymbol{X}^{\boldsymbol{\beta}} \exp(\boldsymbol{X_2 \beta_2}) \quad \text{(Eq. 4)}$$

It was assumed that long-haul and short-haul routes air cargo is affected by the variables in a different way. The panel data was divided into two subsets including routes not farther than 3500km (for a "short-haul") and 3500km or farther (for a "long-haul").[6]

For modelling the **short-haul** (see Eq. 5) air cargo routes (predominantly intra-European), the inflation and tariff variables were excluded as irrelevant. European Economic Area countries do not significantly differ in inflation levels[7] and are participants of the Single Market (no tariffs).[8] **DIST** (distance in 1000s of km) plays some role in this model, but was excluded as irrelevant for long-haul. The recently notorious public debt variable (**DTD**, debt at destination) and a level of credit for private sector (**CTO**, at origin) were included to enrich information on the related economies. The **long-haul** specification (see Eq. 6) assumes a pure exponential functional form was.

$$V_{short} = \alpha \boldsymbol{X}^{\boldsymbol{\beta}} \exp(\beta_5 \boldsymbol{DTD} + \beta_6 \boldsymbol{CTO} + \beta_7 \boldsymbol{IDOC} + \beta_8 \boldsymbol{TTM} + \beta_9 \boldsymbol{DIST}) \quad \text{(Eq. 5)}$$

where X is a n x 4 matrix of GDP and population at origin and destination
n – number of observations
DTD – public debt at destination (% of GDP, values 0 – 1)
CTO – domestic credit to private sector (% of GDP, values 0 – 1)
IDOC – number of required import documents (e.g. 4)
TTM – time to prepare and pay taxes (1000s of hours)
DIST – great circle distance (1000s of km)

5) Westerlund, J., Wilhelmson, F. (2006), pp. 3-6.

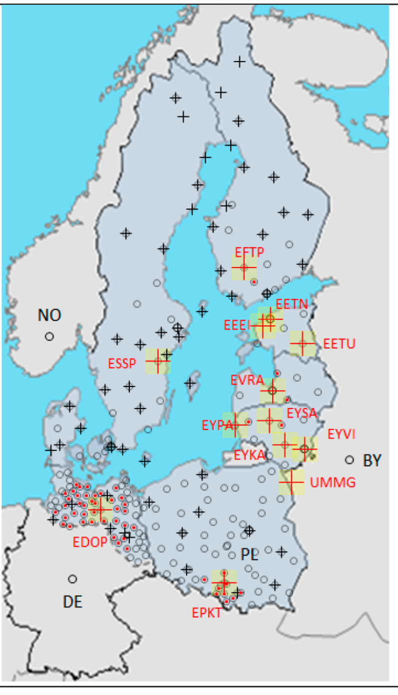
6) according to the EC 261/2004 regulation establishing common rules on compensation and assistance to passengers in the event of denied boarding and of cancellation or long delay of flights, that clearly distinguishes flights on routes 3500km or farther from the others.

7) the convergence criteria, required by Stability and Growth Pact in all 27 EU Member States

8) EEC 2913/1992 regulation establishing the Community Customs Code

$$V_{long} = \alpha \exp(\boldsymbol{\beta X} + \beta_5 \boldsymbol{DTO} + \beta_6 \boldsymbol{CTO} + \beta_7 \boldsymbol{IDOC} + \beta_8 \boldsymbol{TTM} + \beta_9 \boldsymbol{INF} + \beta_{10} \boldsymbol{TRF}) \quad \text{(Eq. 6)}$$

where X is a n x 4 matrix of GDP and population at origin and destination
n – number of observations
DTO – public debt at origin (% of GDP, values 0 – 1)
CTO – domestic credit to private sector (% of GDP, values 0 – 1)
IDOC – number of required import documents (e.g. 4)
TTM – time to prepare and pay taxes (1000s of hours)
INF – economic distance
TRF – tariff level at destination for incoming goods form origin (in percentage points, e.g. 2,5)



Example of a model space (the Baltic Sea Region):

- 71 nodes including 12 focus airports
- 205 NUTS3 regions including 58 with airports
- 61 extra-EU countries
- 6 years of o-d loaded and unloaded air cargo volumes
- ESPON Multimodal Potential Accessibility indicators (EU=100) for NUTS3 region

4. ESTIMATION

A well-known method for model estimation is a Maximum Likeihood Estimation (MLE)[9]. Iterative algorithm in the MLE form selects the set of values of the model parameters that maximizes the likelihood function:

$$\ln \mathcal{L}(\theta\,;\,x_1,\ldots,x_n) = \sum_{i=1}^{n} \ln f(x_i \mid \theta),$$

[9] Eliason S., R. (1993), pp. 28-45.

5. METHODS OF VALIDATION OF RESULTS

To evaluate estimation results for regression models other than the linear model, R-squared type goodness-of-fit summary statistics have been developed for particular models using a variety of methods. One of the adequate measures for the purpose of an exponential form of the gravity model (assuming Normal distribution) is an R-squared measure of goodness of fit for the class of exponential family[10]:

Table 1. R_L for exponential family regression models

Distribution	KL Divergence	R_L	Canonical Link[a]
Normal	$\Sigma(y-\mu)^2/\sigma^2$	$1-\frac{\Sigma(y-\hat{\mu})^2}{\Sigma(y-\bar{y})^2}$	$\mu=\eta$

This R-squared is defined as the proportionate reduction in uncertainty. Under further conditions concerning the conditional mean function it can also be interpreted as the fraction of uncertainty explained by the fitted model.

6. CONCLUSIONS

The well known gravity method may be and is used as a ready-available tool for simple analysis of market potential. It requires a set of explanatory panel data and estimation of parameters using Maximum Likelihood Estimator. The validation is done by comparison of the results with the explained data against which the model was estimated.

The tool will be applied in further analysis of Baltic Sea Region air cargo transport or other purpose air transport calculations at the Institute of Aviation[11] to reveal some general rules associated to the region demand in terms of: distance, Gross Domestic Product level, population and other economic measures as inflation rate, tariff rate, required paperwork, liabilities.

SOURCES

EU regulations:

[1] EEC 2913/1992 - Council Regulation (EEC) No 2913/92 of 12 October 1992 establishing the Community Customs Code

[2] EC 261/2004 - REGULATION (EC) No 261/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 February 2004 establishing common rules on compensation and assistance to passengers in the event of denied boarding and of cancellation or long delay of flights, and repealing Regulation (EEC) No 295/91

EU Policy:

[3] Stability and Growth Pact in all 27 EU Member States- TREATY ON STABILITY, COORDINATION AND GOVERNANCE IN THE ECONOMIC AND MONETARY UNION BETWEEN THE KINGDOM

[10] Cameron, A.C., Windmeijer, F.A.G. (1997), p.8.

[11] Wiśniowski, W., 2014.

OF BELGIUM, THE REPUBLIC OF BULGARIA, THE KINGDOM OF DENMARK, THE FEDERAL REPUBLIC OF GERMANY, THE REPUBLIC OF ESTONIA, IRELAND, THE HELLENIC REPUBLIC, THE KINGDOM OF SPAIN, THE FRENCH REPUBLIC, THE ITALIAN REPUBLIC, THE REPUBLIC OF CYPRUS, THE REPUBLIC OF LATVIA, THE REPUBLIC OF LITHUANIA, THE GRAND DUCHY OF LUXEMBOURG, HUNGARY, MALTA, THE KINGDOM OF THE NETHERLANDS, THE REPUBLIC OF AUSTRIA, THE REPUBLIC OF POLAND, THE PORTUGUESE REPUBLIC, ROMANIA, THE REPUBLIC OF SLOVENIA, THE SLOVAK REPUBLIC, THE REPUBLIC OF FINLAND AND THE KINGDOM OF SWEDEN

Handbooks:

[4] Eliason S., R. (1993), Maximum Likelihood Estimation – Logic and Practice, SAGE.

[5] Manheim, L. M. (1979), Fundamentals of transport Systems Analysis, Volume 1: Basic concepts, The MIT Press.

[6] Train, K. E. (2009), Discrete Choice Methods with Simulation, Cambridge University Press.

Published papers:

[7] Cameron, A.C., Windmeijer, F.A.G. (1997), An R-squared measure of goodness of fit for some common nonlinear regression models, Journal of Econometrics, 77, pp. 329-342.

[8] Westerlund, J., Wilhelmson, F. (2011), Estimating the gravity model without gravity using panel data, Applied Economics, Taylor & Francis (Routledge): SSH Titles, 2009, 43 (6), p. 641.

[9] Wiśniowski, W. (2014), Specjalizacje Instytutu Lotnictwa – przegląd i wnioski, Prace Instytutu Lotnictwa 235, s. 7-16.

MODELOWANIE RYNKU LOTNICZEGO TRANSPORTU TOWAROWEGO – METODA GRAWITACYJNA.

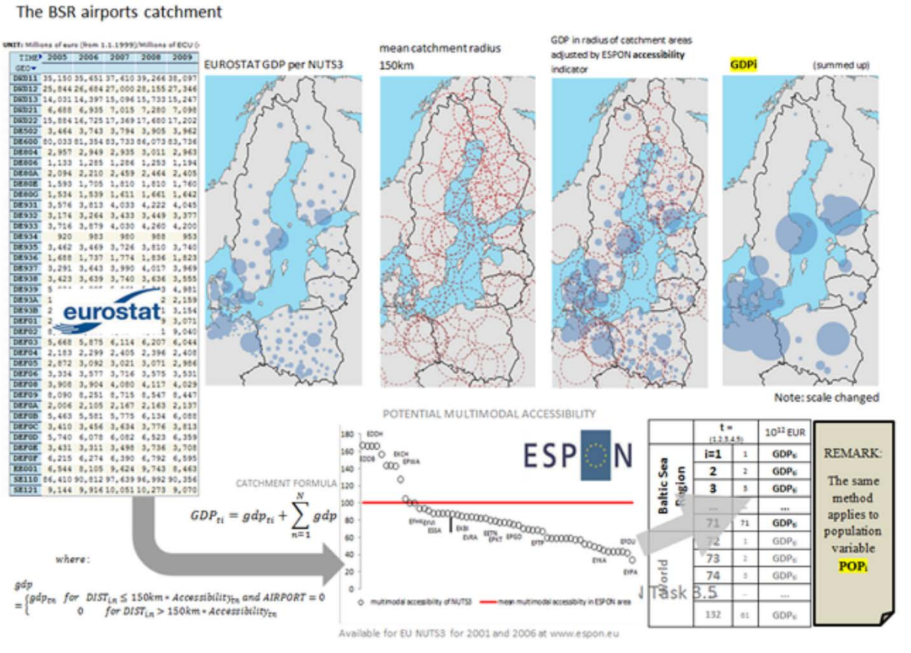
Abstrakt

Metoda grawitacyjna i jej inne wariacje w ekonomii transportu, będące analogią wobec newtonowskiego powszechnego prawa ciążenia, nie są najnowszym narzędziem do szacowania popytu. Są, natomiast, proste i możliwe do zastosowania mając do dyspozycji publicznie dostępne dane takie jak te pochodzące z EUROSTAT lub innych źródeł państwowych. Głównym założeniem metody jest to, że podróże (lub poziom przepływu towarów) są generowane w jednych lokalizacjach i są „przyciągane" do pozostałych lokalizacji zgodnie z pewnym identyfikowalnym wzorcem. Możliwe jest zaproponowanie – ale nie ustalenie jak w newtonowskiej fizyce – tych wzorców pod warunkiem, że jest dostępna pełna lista danych socjoekonomicznych (PKB, ludność, …) lub innych policzalnych warunków w zasięgu (strefie ciążenia) wszystkich lokalizacji (węzłów) powiązana z odpowiadającymi im poziomami przepływów przy użyciu funkcji nieliniowej. Każda ze zmiennych ulokowanych po stronie równania, która opisuje zjawisko (przepływy) jest wyposażona w wagę (w ekonometrii zwaną parametrem). Z powodu nieliniowej formy funkcji parametry są obliczane iteracyjnie, co jest najczęściej wykonywane metodą największej wiarygodności. Trafność dopasowania modelu jest sprawdzana metodami statystycznymi badającymi proporcje redukcji niepewności.

Słowa kluczowe: transport lotniczy, model grawitacyjny, użycie metody największej wiarygodności.

APPENDIX - AIRPORT CATCHMENT

The catchment area method uses ESPON[12] potential multi modal accessibility indicator estimated for 2001 and 2006 for each of the NUTS3 statistical region of the European Union. The figure below presents the reasoning behind the catchment potential summing up.



As ESPON defines "*potential accessibility is a construct of two functions, the activity function representing the activities or opportunities to be reached and the impedance function representing the effort, time, distance or cost needed to reach them (Wegener et al., 2002). For potential accessibility the two functions are combined multiplicatively, i.e. are weights to each other and both are necessary elements of accessibility: Where Ai is the accessibility of area i, Wj is the activity W to be reached in area j, and cij is the generalised cost of reaching area j from area i. Ai is the total of the activities reachable at weighted by the ease of getting from i to j. The interpretation is that the greater the number of attractive destinations in areas j is and the more accessible areas j are from area i, the greater is the accessibility of area i.*"[13]

$$A_i = \sum_j W_j^{\alpha} \exp(-\beta c_{ij})$$

In the analysis o-d distance was adjusted by each of the BSR region multimodal potential accessibility. If inequality was still corresponding: distance * Ai/100 < 150km then region was included to the catchment area and its GDP volume summed up.

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[12] European Spatial Planning and Observatory Network (ESPON), http://www.espon.eu/main/Menu_Projects/Menu_ScientificPlatform/Menu_MapUpdates/accessibility.html

[13] Update of Selected Potential Accessibility Indicators, Final Report, ESPON, 2007, p.7 http://www.espon.eu/export/sites/default/Documents/Projects/ESPON2006Projects/ScientificBriefingNetworking/UpdateOnAccessibilityMaps/espon_accessibility_update_2006_fr_070207.pdf