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THE NEW GENERALIZED GRAVITATIONAL MODEL OF MIGRATION FOR GEORGIA

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Abstract. Econophysics, or the theory of construction of models using physical assumptions in economics, already has a long history. For this purpose, the gravitational law of attraction was probably first used in the modeling of trade models between two subjects. The laws of gravitational and electrostatic attraction were then used to study migration between countries. The article adopts two new models (containing dummy variables) of migration from Georgia to leading European countries and USA using multivariate linear regression. They are based on the Lewer and van der Berg generalized gravitational model of migration between countries of The Organisation for Economic Co-operation and Development (OECD). Their model contains dummy parameters of border, the proximity of the state languages and colonial links in past. In this article we introduce a new dummy parameter «religion» of the model of migration from Georgia; It is hypothesized that migration between neighbor countries may not be analogous to the Newton's law of universal gravitation. In our view, it would be more appropriate to use other physical assumptions to construct such a migration model, for example a mathematical model of the law of equalization of temperatures in an area with different temperatures at different points.

KEYWORDS: ECONOPHYSICS, MIGRATION, GRAVITATIONAL ATTRACTION LAW, ELECTROSTATIC ATTRACTION LAW, DUMMY PARAMETERS.

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Econophysics, or the theory of construction of models using physical assumptions in economics, already has a long history [1]. For this purpose, the gravitational law of attraction was probably first used in the modeling of trade models between two subjects [2-3]. The laws of gravitational and electrostatic attraction were then used to study migration between countries [4-5]. For example, the electrostatic migration model discussed in [4] is

$$M_{ij} = k \frac{q_i \rho_j}{\varepsilon} \frac{a^2}{R^2}, (1)$$

where M_{ij} is a number of migrants from poor i country to rich j country, q_i is the population of a poor country, p_j is the population of a rich country, a is the size (radius) of a rich region, R is the distance between these countries, k is a coefficient of proportionality, ε is a "penetration" of the rich country, i.e. a different barriers.

Let us consider the possibility of applying the migration model proposed in [6] for Georgia. This model calculates the natural logarithm of the number of migrants from a i country to a j country

$$\ln(M_{ij}) = a_0 + a_1 \ln(pop_i \cdot pop_j) + a_2 \ln(dist_{ij}) + a_3(rely_{ij}) + a_4 \ln(stock_{ij}) + a_5 CONT_{ij} + a_6 LANG_{ij} + a_7 LINK_{ij} + u_{ij}, \quad (2)$$

where M_{ij} is a number of migrants from poor i country to rich j country;

$pop_i \cdot pop_j$ is the product of the population of the respective countries;

$dist_{ij}$ is the distance between countries;

$rely_{ij}$ is the ratio of the per capita income of the country j to the per capita income of the country i ;

$stock_{ij}$ is the number of people already emigrating from country i to country j (the larger the already emigrated population is, the easier it is to migrate and adapt);

$CONT_{ij}$ is a dummy parameter of the common border between these two countries;

$LANG_{ij}$ is a dummy parameter of the proximity of the state languages of these two countries;

$LINK_{ij}$ is a dummy parameter of colonial links in past between these two countries;

u_{ij} is the error function.

Let us note that the value of the dummy parameter is 1 or 0, depending on whether the condition is fulfilled or not; For example, if the source country was a colony of the destination country, the dummy parameter is equal to 1, otherwise it is equal to 0. In the model under consideration, $CONT_{ij}$, $LANG_{ij}$ and $LINK_{ij}$ are dummy parameters.

In this model it is expected that a_2 is negative.

In the article [6] the coefficients from (2) estimates based on migration data between countries of The Organisation for Economic Co-operation and Development (OECD); This organization includes the following 25 countries: Australia, Austria, New Zealand, Belgium, United Kingdom, Germany, Canada, Denmark, Spain, Turkey, Japan, Ireland, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Greece, France, Finland, United States, Switzerland, Sweden. According to [6], these coefficients are:

$$a_0 = 4.218, a_1 = 0.221, a_2 = -0.261, a_3 = 0.00004, a_4 = 0.401, a_5 = -0.091, a_6 = 0.275, a_7 = 0.288.$$

Therefore (2) formula will take the following form:

$$\begin{aligned} \ln(M_{ij}) = & 4.218 + 0.221 \cdot \ln(pop_i \cdot pop_j) - \\ & -0.261 \cdot \ln(dist_{ij}) + 0.00004 \cdot (rely_{ij}) + \\ & +0.401 \cdot \ln(stock_{ij}) + 0.275 \cdot Lang_{ij} - \\ & -0.091 \cdot CONT_{ij} + 0.288 \cdot LINK_{ij} + u_{ij}. \end{aligned} \quad (3)$$

We are using (3) formula to study migration from Georgia. According to the World Bank [7], there were 4,9000,000 people living in Georgia in 1995; This period is relevant for our purposes, because at that time the Russian-speaking population had left Georgia. The population of the countries of our interest, and the distance between Tbilisi and the capitals of these countries, can be found on the Internet. The World Bank tables [8], which give the GDP per capita from 1960-2017, can be used to determine the GDP per capita by countries.

Table 1. Official Statistics on Migration from Georgia (in thousands) - [9]

Year	Sum	Russia	Greece	Ukraine	Azerbaijan	Armeny	USA	Germany	Cyprus	Italy	Israel, Spain, Turkey
2017	840	450	80	70	50	40	30	20	20	10	1 to 10
2000	910	630	70	70	60	50	10				20
1990	880	660		80	70	40					30

To evaluate the results of the formula (3), we need to know the number of emigrants from Georgia to different countries. Unfortunately, the official data and the unofficial statistical data of the Office of the State Minister of Georgia for Diaspora Issues differ significantly (see Tables 1 and 2).

Table 2. Unofficial statistics of the Ministry of Diaspora - 2015;

The total number of emigrants is approx. 1,600 thousands in 42 countries [9-10].

Russia	800000	Italy	12124	Switzerland	2000	Moldova	500
Greece	250000	Israel	10000	Armeny	1000	Romania	500
Ukraine	150000	Autriche	10000	Bulgaria	1000	Slovakia	500
Turkey	100000	Kazakhstan	7000	Czechia	1000	Estonia	500
USA	80000	Cyprus	7000	Hungary	1000	Lithuania	500
Azerbaijan	35000	Belarus	5000	Finland	1000	Lietuva	300
Spain	30000	Nederlands	5000	Norway	1000	Kyrgyzstan	200
Germany	25000	Uzbekistan	4000	Danmark	1000	Japan	100
Belgium	20000	Portugal	3000	Irland	1000	Australia	20
France	20000	Sweden	3000	Canada	1000		
UK	15000	Poland	2000	Tajikistan	500		

Table 3. Migration from Georgia with 1995 data and amended by a_4 and stock.

P.R.C. - Research Center; Diasp. - Unofficial data of the Ministry of Diaspora

	Migrants (thous.)		pop (mill.)	dist (km)	GDP PPP	rel	Compatriots	a3	Lang	cont	Link	ln(Mij)	Mij
	P.R.C.	Diasp.											
Sum	840	1608	4.9		1,884								
Georgia	0	0	4.9	0	1,884								
Russia	450	800	160	1648	5613	3.30	100000	0.00004	1	1	1	14.9528	3118289
Russia	450	800	160	1648	5613	3.30	100000	0.04	1	1	1	15.0845	3557260
Russia	450	800	160	1648	5613	3.30	100000	0.004	1	1	1	14.96585	3159256
Russia	450	800	160	1648	5613	3.30	100000	0.00004	0	1	0	14.3898	1775859
Russia	450	800	160	1648	5613	3.30	14000	0.00004	0	1	0	13.60138	807246
USA	30	80	329	9300	28691	16.85	10	0.00004	0	0	0	10.49566	36158
Greece	80	150	10.8	1845	15,404	9.05	1000	0.00004	0	0	0	12.00947	164304
Turkey	8	100	80.8	1024	10,383	4.40	100	0.00004	0	1	0	11.59307	108344
Ukraine	70	150	42.5	1467	3,987	2.18	500	0.00004	0	0	0	12.09374	178749
Azerb.	50	35	10	448	2511	1.47	80	0.00004	0	1	0	11.25745	77455
Armen.	40		3	170	1592	0.93	30	0.00004	0	1	0	10.85234	51655
Germany	20	25	80	2641	23,521	13.85	2	0.00004	0	0	0	9.866214	19268
Cyprus	20		0.5	2629	17,065	10.02	100	0.00004	0	0	0	10.31436	30163
Italy	10		59.6	2669	22,353	13.09	20	0.00004	0	0	0	10.7216	45325
Spain		30	46.7	4025	16,258	9.52	100	0.00004	0	0	0	11.20583	73558

Table 4. Migration from Georgia with 1995 data and amended by a_4 and stock.
P.R.C. - Research Center; Diasp. - Unofficial data of the Ministry of Diaspora (continuation of Table 3).

	Migrants (thous.)		pop (mill.)	dist	GDP PPP	rel	Compatri ots	a3	Lang	cont	Link	ln(Mij)	Mij
	P.R.C.	Diasp.											
Sum	840	1608	4.9		1,884								
Georgia	0	0	4.9	0	1,884								
Russia	450	800	160	1648	5613	3.30	1	0.00004	1	1	1	10.33611	30826
Russia	450	800	160	1648	5613	3.30	1	0.04	1	1	1	10.46782	35165
Russia	450	800	160	1648	5613	3.30	1	0.004	1	1	1	10.34916	31231
Russia	450	800	160	1648	5613	3.30	1	0.00004	0	1	0	9.773112	17555
Russia	450	800	160	1648	5613	3.30	1	0.00004	0	1	0	9.773112	17555
USA	30	80	329	9300	28691	16.85	1	0.00004	0	0	0	9.572321	14362
Greec	80	150	10.8	1845	15,404	9.05	1	0.00004	0	0	0	9.239464	10296
Turkey	8	100	80.8	1024	10,383	4.40	1	0.00004	0	1	0	9.746395	17093
Ukraine	70	150	42.5	1467	3,987	2.18	1	0.00004	0	0	0	9.601678	14790
Azerb.	50	35	10	448	2511	1.47	1	0.00004	0	1	0	9.500256	13363
Armen.	40		3	170	1592	0.93	1	0.00004	0	1	0	9.488459	13206
Germany	20	25	80	2641	23,521	13.85	1	0.00004	0	0	0	9.588262	14592
Cyprus	20		0.5	2629	17,065	10.02	1	0.00004	0	0	0	8.467684	4758
Italy	10		59.6	2669	22,353	13.09	1	0.00004	0	0	0	9.520316	13634
Spain		30	46.7	4025	16,258	9.52	1	0.00004	0	0	0	9.359152	11605

Based on Formula (3) and using the above databases, we can now evaluate the effectiveness of Formula (3) to describe emigration from Georgia (see Tables 3 and 4); All you have to do is use the appropriate tools in Ms Excel.

According to a study by the Pew Research Center, one of the most competent organizations in the United States, 450,000 people migrated from Georgia to Russia in 1995-2015, while according to unofficial data from the Ministry of Diaspora, this number is almost twice greater and is equal to 800,000 (Table 4). The situation is similar when determining the number of migrants in other countries; We can consider the example of the United States, where 30 thousand people migrated according to the data of the US Research Center, while the data of the Ministry of Diaspora is equal to 80 thousand migrants. Accordingly, these data were 80 thousand and 150 thousand for Greece (250 thousand people left Georgia for Greece, but 100 thousand of them were ethnic Greeks), and for Ukraine 70 thousand and 150 thousand. The total number of migrants, according to the Pew Research Center, were 840 thousand people, while according to unofficial data from the Ministry of Diaspora, this number is almost 2 times greater than the data of the Pew Research Center and is equal to 1607 thousand people. In our opinion, the data of the Ministry of Diaspora is more in line with reality, which is confirmed by the results of the general population census. From these data we can conclude that it is very attractive, affordable and easy for the population of Georgia to migrate and adapt to Russia, Greece, Ukraine and the United States.

In Table 3 and Table 4, we calculate the number of emigrants from Georgia according to the gravitational model of [6]. Data that affect the magnitude of migration are considered. These are: population, distance between capitals, ratio of GDP per capita to GDP, number of people already emigrating from country to country, dummy parameter of common border between two countries; A dummy parameter of the proximity of the state languages of the two countries; The dummy parameter of the colonial link between the two countries.

Analyzing the emigration from Georgia, we can conclude from Table 4 that although some parameters have varied, namely the number of compatriots already residing in the host countries (column 7), the coefficient of rel_{ij} (column 8) and dummy parameters, 3 and 4 tables show that **(6) model does not adequately reflect the number of emigrants from Georgia to different countries.**

So, we decided to recalculate the coefficients of (6) model using linear regression of multiple variables containing dummy parameters, using the appropriate tools in MS Excel; At the same time, we added a new dummy parameter – “Relig”, which takes the value of 1 when countries have a common religion, otherwise it is equal to 0. Also, we removed the dummy parameter

of the existence of a common language, because Georgia has no common language with any of the countries listed below. We considered that, although at some point almost all Georgian citizens knew at least a little Russian, there was no reason to consider Russian as a common language of Russia and Georgia (unlike Tables 3 and 4). At the same time, the list of countries, in which migration was studied, was expanded, although Armenia and Azerbaijan were excluded, as migration was clearly ethnic in nature.

Table 5. 1995 data from World Bank statistics [8].

1,995	Diasp	POP	dist	GDP PPP	Compatr									
Georgia		4,900,000		1,884	STOCK	ln(Diasp)	ln(POP _i POP _j)	Ln(dist)	rel	ln(STOCK)	cont	Link	Relig	ln(M _{ij})
Russia	800,000	160,000,000	1,648	5,613	100,000	13.592	34.295	7.407	2.979	11.513	1	1	1	13.647
USA	80,000	329,000,000	9,300	28,691	1,000	11.290	35.016	9.138	15.229	6.908	0	0	0	11.004
Greece	150,000	10,816,000	1,845	15,404	3,000	11.918	31.601	7.520	8.176	8.006	0	0	1	11.214
Turkey	100,000	80,811,000	1,024	10,383	1,500	11.513	33.612	6.931	5.511	7.313	1	1	0	11.459
Ukraine	150,000	42,542,000	1,467	3,987	10,000	11.918	32.971	7.291	2.116	9.210	0	0	1	12.077
Germany	25,000	80,000,000	2,641	23,521	1,000	10.127	33.602	7.879	12.485	6.908	0	0	0	10.233
Cyprus	7,000	500,000	2,629	17,065	500	8.854	28.527	7.874	9.058	6.215	0	0	1	9.345
Italy	12,000	59,571,000	2,669	22,353	1,000	9.393	33.307	7.889	11.865	6.908	0	0	0	10.040
Spain	30,000	46,700,000	4,025	16,258	1,000	10.309	33.064	8.300	8.630	6.908	0	0	0	9.874
Belgium	20,000	11,200,000	3,229	22,405	300	9.903	31.636	8.080	11.892	5.704	0	0	0	9.069
France	20,000	66,700,000	3,372	20,740	1,500	9.903	33.420	8.123	11.008	7.313	0	0	0	10.038
UK	15,000	64,100,000	3,542	20,516	1,000	9.616	33.381	8.172	10.890	6.908	0	0	0	10.071
Austria	10,000	8,500,000	2,339	23654	400	9.210	31.360	7.757	12.555	5.991	0	0	0	8.863
Netherlands	5,000	17,419,000	3,203	23403	300	8.517	32.078	8.072	12.422	5.704	0	0	0	9.363
Israel	10,000	9,241,000	1,396	19,892	500	9.210	31.444	7.241	10.558	6.215	0	0	0	8.977
All	1607744													155.274

The data in Table 5, as noted, belong to 1995. Its first column is the list of countries, the second column (Diasp) is according to unofficial data of the Ministry of Diaspora the number of Georgian emigrants in these countries, the column ends with the total number of emigrants 1607744. The third column is the population in the respective countries, the fourth column is the distance from Tbilisi to the capitals of the respective countries, the fifth column is the gross domestic product of the respective countries, the sixth column is the number of compatriots before migrating to the respective countries, the seventh column is the logarithms of the second column data with natural base, the eighth column consists of natural logarithms of the population of Georgia and the respective country, the tenth column consists of the ratio of the GDP of the respective country and the GDP of Georgia, the eleventh column consists of the natural logarithms of the sixth column (number of compatriots before migration), the twelfth column is the dummy parameter of the common border, the thirteenth column is the colonial link in past dummy parameter, the fourteenth column is a parameter of the common religion, the fifteenth column consists of the approximate numbers of emigrants in the respective countries, calculated by the formula (4) obtained by using multivariate regression instrument of MS Excel.

The data in Table 5, using MS Excel's Data>Regression function, gives us the corresponding values of the coefficients of gravitational model of migration at 95% confidence interval, given in Table 6. The column in this table, called Coefficients, gives us a model of migration from Georgia obtained by regression:

$$\ln(M_{ij}) = -10.458 + 0.683\ln(POP_i \cdot POP_j) - 0.121\ln(dist) - 0.015rel - 0.160\ln(STOCK) + 1.061Link + 2.413Relig. (4)$$

The coefficient with "cont" is zero because the columns "cont" and "Link" coincide. The last column of Table 5 shows the number of people emigrating from Georgia to the respective countries, which is calculated by formula (4). Comparison of the obtained values with the data of the Ministry of Diaspora shows the advantage of formula (4).

Table 6

SUMMARY OUTPUT								
<i>Regression Statistics</i>								
Multiple R	0.939027							
R Square	0.881772							
Adjusted R Square	0.668101							
Standard Error	0.640622							
Observations	15							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	7	24.48672	3.498103	9.944332	0.003574038			
Residual	8	3.283173	0.410397					
Total	15	27.7699						
	Coefficien	Standard E	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-10.4584	6.550357	-1.59662	0.149018	-25.56355608	4.64674276	-25.56355608	4.646742762
ln(POPi.POPj)	0.682748	0.308773	2.211169	0.057975	-0.029282399	1.39477914	-0.029282399	1.39477914
Ln(dist)	-0.12078	0.581428	-0.20772	0.840636	-1.461551184	1.21999936	-1.461551184	1.219999361
rel	-0.01543	0.11416	-0.13517	0.895813	-0.278685571	0.2478225	-0.278685571	0.247822505
ln(STOCK)	-0.1601	0.440778	-0.36322	0.725852	-1.176534271	0.85633711	-1.176534271	0.856337113
cont	0	0	65535	#NUM!	0	0	0	0
Link	1.061203	0.74545	1.423574	#NUM!	-0.65780764	2.7802138	-0.65780764	2.7802138
Relig	2.4126	1.190618	2.026343	0.077294	-0.3329697	5.15817033	-0.3329697	5.158170328

As we can see, the coefficient with "rel" and "ln (STOCK)" is negative, i.e. more income and a common border do not promote migration, but vice versa. We think the reason for this is that migration between neighbor countries may not be described by the law of gravitational attraction because determining the distance between these countries as the

Table 7

1,995	Diasp	POP	dist	GDP PPP						
Georgia		4,900,000		1,884	ln(Diasp)	ln(POPi.P OPj)	Ln(dist)	rel	Relig	ln(Mij)
USA	80,000	329,000,000	9,300	28,691	11.290	35.016	9.138	15.229	0	11.02244
Greece	150,000	10,816,000	1,845	15,404	11.918	31.601	7.520	8.176	1	11.24413
Ukraine	150,000	42,542,000	1,467	3,987	11.918	32.971	7.291	2.116	1	12.07271
Germany	25,000	80,000,000	2,641	23,521	10.127	33.602	7.879	12.485	0	10.22303
Cyprus	7,000	500,000	2,629	17,065	8.854	28.527	7.874	9.058	1	9.373613
Italy	12,000	59,571,000	2,669	22,353	9.393	33.307	7.889	11.865	0	10.0437
Spain	30,000	46,700,000	4,025	16,258	10.309	33.064	8.300	8.630	0	9.873328
Belgium	20,000	11,200,000	3,229	22,405	9.903	31.636	8.080	11.892	0	9.026268
France	20,000	66,700,000	3,372	20,740	9.903	33.420	8.123	11.008	0	10.09997
UK	15,000	64,100,000	3,542	20,516	9.616	33.381	8.172	10.890	0	10.07354
Austria	10,000	8,500,000	2,339	23654	9.210	31.360	7.757	12.555	0	8.875542
Netherlands	5,000	17,419,000	3,203	23403	8.517	32.078	8.072	12.422	0	9.293949
Israel	10,000	9,241,000	1,396	19,892	9.210	31.444	7.241	10.558	0	8.946923
All		1607744								

distance between their capitals is not correct. Therefore, we removed Russia and Turkey from Table 5, which was followed by the removal of the common border column, because Georgia does not have a common border with other countries; Also, we removed the

Table 8

SUMMARY OUTPUT								
<i>Regression Statistics</i>								
Multiple R	0.8803692							
R Square	0.77505							
Adjusted R Square	0.662575							
Standard Error	0.6369501							
Observations	13							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	4	11.18264364	2.795661	6.890864	0.010499028			
Residual	8	3.245643271	0.405705					
Total	12	14.42828691						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-9.713269	4.928701494	-1.97076	0.084245	-21.078875	1.6523371	-21.07887495	1.652337102
ln(POPi.POPj)	0.6035653	0.161679948	3.733087	0.005762	0.230730712	0.9764	0.230730712	0.976399971
ln(dist)	-0.046002	0.576278413	-0.07983	0.938336	-1.3749028	1.282898	-1.374902803	1.282898004
rel	0.0014074	0.111500673	0.012622	0.990238	-0.25571363	0.2585284	-0.255713625	0.2585284
Relig	2.2183987	0.745362854	2.976267	0.017701	0.499588912	3.9372086	0.499588912	3.937208557

corresponding column of compatriots, resulting in Table 7; Using MS Excel's Data> Regression function according to Table 7 will give you the values given in Table 8 at 95% confidence intervals:

The column in this table, called “Coefficients”, gives us a model of migration from Georgia obtained by regression:

$$\ln(M_{ij}) = -9.713 + 0.604\ln(POP_i.POP_j) - 0.046\ln(dist) + 0.0014rel + 2.219Relig. (5)$$

Comparing the values calculated by the formula (4) of the population emigrating from Georgia to the respective countries with the data of the Ministry of Diaspora in the last column of Table 5 shows that formula (5) is not characterized by the shortcomings of formula (4). However, migration to Russia and Turkey is not calculated by this formula.

Thus, the article adopts two new models of migration from Georgia to leading European countries through formulas (4) and (5) obtained by multivariate linear regression and containing dummy variables, including a new dummy parameter «religion“. It is hypothesized that migration between neighbor countries may not be analogous to the gravitational law of gravity; In our view, it would be more appropriate to use other physical assumptions to construct such a migration model, for example a mathematical model of the law of equalization of temperatures in an area with different temperatures at different points.

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