СВІТОВЕ ГОСПОДАРСТВО

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SPECIFICS OF GAINING ECONOMIC INDEPENDENCE BY REFUGEES FROM UKRAINE

The article examines the problems of the emergence and development of the flow of refugees from Ukraine during the first half of 2022 as a complex phenomenon that depends on rational (economic) and irrational (social-psychological) factors. The phenomenological model, created on the basis of the Burgers' equation, which reproduces the process of the involvement of the new refugees to the flow and the resistance of the environment to the formation of this flow, made it possible to analyze such subtle effects as the existence of a hub country, where the initial accumulation of refugees takes place, followed by redistribution, and the influence of infrastructure problems in the exit country. Transitional regimes from the infrastructural problems prevailing in the country of exit to the predominant influence of the hub-country effects are also considered. It is concluded that the entry to new levels of the refugee flow could be achieved due to the effects of emotional and economic (rational) behavior of refugees replenishing the hub, i.e., a stepwise development of the refugee flow is possible if new hubs would be created, or the existing hub will be freed up from overloading. On the basis of mathematical modeling, it is shown that in the case when the refugee flow is restrained by infrastructural problems in the exodus country, the exit to the stationary regime is delayed. Identification of the proposed model was carried out based on the empirical data on the refugee flow development using the apparatus of incorrect problems of the mathematical physics. A comparison of the dynamic effects of the refugee flow development from Ukraine with similar processes in Syria and Iraq was carried out, which allowed for identification of the zones of influence of infrastructure problems and the hub effect in the refugee flow development. The use of the concept of refugees' economic independence (self-sufficiency), which was developed in 2018 by the Office of the United Nations High Commissioner for Refugees, was proposed as a basis for policy formation in the field of refugee assistance. The consequences of the discrete use of this concept in the case of refugees from Syria are analyzed, and the dynamics of employment opportunities for these refugees in countries with similar and different socio-cultural conditions were compared. A conclusion was made about the fundamental difference in the employment trends in those types of countries. The authors formulated proposals regarding the utilization of the Monte Carlo methods and the learning model for researching the peculiarities of the process of Ukrainian refugees achieving a

certain level of economic independence (self-sufficiency), determining the typical time of reaching such a level, obtaining the distribution of probabilities of getting the first job depending on the initial competencies and skills of refuges, their education, experience, and foreign languages mastery.

Keywords: refugee flow from Ukraine, refugees' economic independence (self-sufficiency), phenomenological modeling, Burger's equation, optimization, ill-posed (inverse) problems of mathematical physics, hub effect, infrastructural problems, rational and emotional problems of refugees

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У статті досліджуються проблеми виникнення та розвитку потоку біженців з України протягом першої половини 2022 р. як складного явища, що залежить від раціональних (економічних) та ірраціональних (соціально-психологічних) чинників. Феноменологічна модель, створена на основі рівняння Бюргерса, яке відтворює процес залучення до потоку нових біженців та опір середовища до формування цього потоку, дозволила проаналізувати такі тонкі ефекти, як існування країни-хабу, де відбувається первинне накопичення біженців з наступним перерозподілом, та вплив інфраструктурних проблем у країні виходу. Розглянуті також перехідні режими від превалювання інфраструктурних проблем у країні виходу до переважного впливу ефектів хабу. Зроблено висновок про те, що вихід на нові рівні потоку біженців досягається за рахунок ефектів емоційної та економічної (раціональної) поведінки біженців, що поповнюють хаб, тобто можливе ступінчасте поводження потоку біженців, якщо буде створюватися новий хаб, або існуючий хаб буде звільнятися від перезавантаження. На підставі математичного моделювання показано, що у разі коли потік біженців стримується інфраструктурними проблемами в країні, вихід на стаціонарний режим затримується. Ідентифікація запропонованої моделі проводилася на основі емпіричних даних щодо нарощування потоку біженців за допомогою апарату некоректних задач математичної фізики. Проведене співставлення динамічних ефектів формування потоку біженців з України з аналогічними процесами стосовно Сирії та Іраку, на основі якого ідентифіковані зони впливу інфраструктурних проблем та ефекту хабу у формуванні потоку біженців. У якості основи для формування політики у галузі допомоги біженцям запропоновано використання концепції економічної самодостатності біженців, що була розроблена у 2018 р. Управлінням верховного комісару по справам біженців ООН. Проаналізовано наслідки дискретного використання даної концепції у випадку біженців з Сирії, проведене співставлення динаміки можливостей працевлаштування цих біженців у країнах з близькими та віддаленими соціально-культурними умовами. Зроблено висновок про принципову відмінність трендів щодо працевлаштування у цих групах країн. Сформульовані пропозиції щодо використання методів Монте-Карло та моделі навчання для дослідження особливостей процесу досягнення українськими біженцями певного рівня економічної самостійності або самозабезпеченості, визначення типового часу досягнення такого рівня, отримання розподілу ймовірностей влаштування на першу роботу залежно від початкових компетенцій та навичок біженців, їх освіти, досвіду й володіння іноземними мовами.

Ключові слова: потік біженців з України, економічна самодостатність біженців, феноменологічне моделювання, рівняння Бюргерса, оптимізація, некоректні задачі математичної фізики, ефект хаба, інфраструктурні проблеми, раціональні та емоціональні проблеми біженців

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Intro & Research goals formulation. Since the beginning of the unprovoked Russian aggression, more than 13 million people have left Ukraine, about 7.5 million of whom are registered as refugees, and another 4.1 million receive temporary protection or use similar national protection schemes in Europe. Educated, intelligent, skillful, and experienced people found themselves completely unexpectedly in a situation where they had to leave their homes in order not to risk their lives and/or to move their children to a safe place. Helping these people overcome the psychological shock, regain self-confidence and integrate into economic/labor activities in a new country is currently a huge challenge. EU countries are making huge efforts to help these people. Despite

this, the process of the Ukrainian refugees' integration in the EU countries is complex and resource intensive.

The vast majority of Ukrainian refugees who left the country with the start of unprovoked Russian aggression, as already mentioned, are educated, intelligent, skillful, and experienced people, most of them are women with children. In the first weeks of the aggression, the EU countries provided all kinds of assistance to the Ukrainians without any economic considerations, regarding this as a kind of moral duty to the citizens of a country, which is defending common values and its own freedom. But later, when the flow of refugees began to number millions of people, the EU countries themselves began to experience certain problems with reception of refugees and are currently looking for a balanced policy in this direction. According to the authors, such a policy should be implemented based on the concept of refugees' economic independence (self-sufficiency), which was developed in 2018 by the Office of the High Commissioner for Refugees (UNHCR) (United Nations, 2018). Currently, this is the only systematic document that reflects a great deal of experience in working with refugees from different countries, at different times and under different circumstances (Micinski, 2021). Therefore, it is very relevant to study the peculiarities of the process of Ukrainian refugees gaining a certain level of economic independence or self-sufficiency, to determine the typical time of reaching such a level, to obtain the distribution of probabilities of obtaining a first job depending on the initial competencies and skills, education, experience and foreign language skills, and to create a dynamic model of this process that would allow for phenomenological analysis of various scenarios of the formation and development of the refugees flow under different circumstances.

Preliminary theoretical analysis. There are significant differences in the economic behavior of Ukrainian refugees due to differences in the social status, marital status, income (property status), psychological status, etc. In addition, the most important problems faced by Ukrainian refugees differ depending on these peculiarities. Given this, a flexible approach should be developed to address possible unique variations in the economical behavior of individual refugees with regards to such features. Undoubtedly, this will facilitate the process of refugees gaining economic independence (self-sufficiency). Besides, such an approach should be based on the identification of systematic factors that determine the general behavioral trends that form certain "patterns of attitude" of refugees belonging to the same behavioral group.

Given the lack of extensive empirical data specifically on Ukrainian refugees, it is only possible to refer to the experience arising from the dynamics of refugee flows from other countries. The closest example in terms its temporal relevance is the flow of refugees from Syria, which intensified in 2015 and continues up to this day, see for example (Grätz *et al*., 2016). Despite the fact that the migration process from Ukraine differs from the exodus from the MENA countries, these countries provide the only empirical base that can be referred to. For example, the trend, that the most popular destination among MENA refugees are the most developed European economies rather than the nearest countries which are not only close geographically but also similar in language, religion, and national values, equally applies to the outflow of refugees from both Syria and Ukraine. In the case of Syrian refugees, Germany and the Scandinavian countries, which are characterized by high levels of social standards, became the most popular destination for the flow of refugees – see for example (Bailey *et al*., 2022). In the case of Ukrainian refugees, Poland is beyond the competition because it is both geographically close and provides attractive social standards for refugees (Kowalski, Lytvynenko *et al*., 2022). Although countries that not only provide high social standards, but also have a demand for skilled workers, as a rule, immigrants from Ukraine are far behind (nat.kozlova@4service-group.com, 2022). It should be noted that in the case of Syria, neither Jordan, not Turkey, nor other

countries of the Middle East close in terms of religion and culture, have turned into an attractive place of refuge like it happened with Poland which has become an asylum for Ukrainians (UNHCR, 2022) and remains a hub where refugees stay for a short time, seeking to leave for countries with higher social standards, where many compatriots have already settled – see (UN Refugee Agency, 2022) for empirical data. Even with relatively modest support provided to refugees from Ukraine, countries such as the UK, Italy, Spain and France are very popular destinations, unlike the "youngest" members of the European Union, such as Romania, Slovakia, etc., even despite their geographical proximity to Ukraine (UNHCR, 2022). At the same time, if we set up for a phenomenological approach development which includes all the factors that have a significant impact on the process, then a certain analogy should be selected that corresponds to the general patterns of the process development being studied. According to the authors, in accordance with the properties of the process of forced migration, several phenomenological approaches to its modeling can be proposed, which reproduce its general regularities:

- mathematical model of transport with dissipation,
- mathematical model of the learning process,
- a stochastic model based on the Monte Carlo method.

In general, the problems of Ukrainian refugees, which need to be formalized by the mathematical model being developed, can be divided into rational and emotional. In this study, we will mainly focus on the rational problems, in particular:

- problems of leaving country of exodus;
- the overload of the social services in recipient hub-country;
- problems with finding the first job in the recipient country, which would correspond to the level of education, skills and experience of a particular refugee;
- bureaucratic barriers.

There are also emotional (irrational) problems affecting the behavior of refugees, which primarily include:

- uncertainty, hopelessness, lack of plans;
- problems of communication with the homeland;
- communication problems in the hosting community;
- psychological problems, depression, stress;
- misunderstanding of the social or cultural features of another country;
- great homesickness.

According to the authors, some of these problems are very difficult to interpret mathematically, so they will remain outside our attention, but most important ones will be treated below.

The mathematical model based on transport with dissipation. The model equation for the analysis of the process of refugee flow formation includes convective transport mechanism with dissipation, that is, the dissipation of transfer energy. It has the following form (1):

$$\frac{\partial U}{\partial \tau} + U \cdot \frac{\partial U}{\partial x} = \frac{\partial}{\partial x}\left[R(x) \cdot \frac{\partial U}{\partial x}\right] \quad (1)$$

$$\frac{\partial R}{\partial \tau} + U \cdot \frac{\partial R}{\partial x} = \mu \cdot \frac{\partial^2 R}{\partial x^2} \quad (2)$$

$$U(x,0) = \text{Heavyside}_\theta(x) = \begin{cases} 0, x < 0 \\ 1, x > 0 \end{cases} \quad (3)$$

$$R(x,0) = F(x) \quad (4)$$

where U – specific intensity of the refugee flow,

R – resistance to refugee flow rising,

τ – pseudo time,

m – intensity of resistance changes to the refugee flow,

$F(x)$ – a function that specifies the initial conditions for the resistance,

x – generalized coordinate.

Equations (1) and (2) form a system of nonlinear one-dimensional convective-diffusion transport equations for the vector quantity U with non-constant dissipation R. Equations (3)-(4) give the initial and boundary conditions for the system (1)-

(2). System (1)-(2) is a simplification (special case) of the system of nonlinear equations of an incompressible viscous continuous medium motion to the case of the one "spatial" variable, known as the Burgers' equation, see for example (Kee & Ong, 2011). This approximation is widely used as a model equation in the study of "shock" turbulent flows of an incompressible continuous medium, when it is necessary to analyze the propagation of the "wave front", that is, the section where an abrupt transition from one state to another occurs, considering the dissipation of the energy of the "shock", (see Surhone et al., 2010, for examples). It should be noted that such a phenomenological approach very reliably reproduces the situation with refugees – the number of people leaving the country changes abruptly from being almost 0 and stabilizes at a certain constant value over a very short time, which is determined by both internal and external conditions. The phenomenological properties of equation (1) are widely used not only in hydrodynamics and related fields, but also apply to the case of dissimilar phenomena, where the ability of this model to describe a fast transition between successive states of the system, accompanied by the dissipation of "energy" is in demand. In a similar form, but with constant dissipation, this equation was used:

- as a phenomenological model of traffic jams;
- as a model of biological invasion;
- to describe a filtration process *etc.*

In a certain sense, the phenomenological properties of the Burgers' equation led to the formulation of the Black-Scholes model (see, for example, Capiński & Kopp, 2013), widespread in the financial activity simulation, where the effects of "convection", "diffusion" and fading (scattering) are also considered, and in turn to the famous formula for determining the price of European options with finite conditions.

The Cole-Hopf transformation, who proved that this equation cannot exhibit chaotic (unstable) behavior, allows for solving the Burgers equations (1) in the R=const approach with initial conditions given by (3), see for example (Lundvall & Weinerfelt, 2004). The exact solution to the (1) is expressed in terms of the so-called "error function", *Erf*, which is the antiderivative of the function e^{-x^2}, that doesn't have an analytical expression (*Erf* values are calculated either numerically or using residue theory). As a result, the solution to the equation (1) with R=const assumption has the following form:

$$U(x,\tau)=\frac{1}{1+\frac{e^{-\frac{\tau-2x}{4R}}\left(1+Erf\left(\frac{\tau-x}{2\sqrt{R\tau}}\right)\right)}{1+Erf\left(\frac{\tau-x}{2\sqrt{R\tau}}\right)}} \qquad (5)$$

Model (1)-(2) with initial conditions (3), which correspond to the piecewise Heaviside q-function, is a description of the "smoothing of the gap" in pseudo time τ and is indeed a good phenomenological approximation to the analysis of the process of the refugee flow increasing in the first moments after the emergence crisis situation with a subsequent decrease in the intensity of that flow with the stabilization at the achieved level. If we proceed from the fact that all future refugees made the decision to leave the country immediately after the outbreak of the battle (this effect is precisely conveyed by the piecewise Heaviside q-function, which instantly changes its value from 0 to 1 at τ>0), all the same they will not be able to implement this decision instantly and simultaneously, which in turn leads to a smoothing of the gap, when the flow of refugees at the initial period of time increases very rapidly, but still with the finite speed, determined by various obstacles (both rational and emotional) and certain resistance factors associated with the insufficient infrastructure capacity.

The change in the dissipation level, which is described by the equation (2) with initial and boundary conditions (4) has the following meaning – at the initial stages of the exodus, resistance in the recipient countries is minimal and the refugee flow is determined by the "indecisiveness" of the refugees themselves (that is, emotional problems) and infrastructural obstacles within the country of origin, while refugees are still leaving the country in increasing numbers.

Approaching the maximal, terminal value, resistance increases due to the saturation effect in the countries which are hosting refugees. In this case, those potential refugees who, for various reasons, did not have time to leave the country at the initial stage of the exodus, may reconsider their decision, being afraid of the problems in the host countries. This effect can be especially powerful in cases when there is a certain hub country, where the broad mass of the refugees initially come to moving afterwards to other destinations. In such a country problem with a social and infrastructure services overload will arise rapidly. As a result, instead of being a hub, such a country can constitute an additional barrier on the refugees' passage. Until the moment when the process of exodus has begun, these peculiarities will not appear, therefore, as an initial condition for resistance to the refugee flow, the hypothesis of R=const has been introduced. The level of R=const corresponds to a certain natural level of decision-making inertia and a reluctance in this decision implementing. That makes it possible to use the exact solution of equation (1) in the form (5).

The dimensionless intensity of the refugee flow is defined as the ratio of the current number of refugees to some stabilized value, which the flow reached after certain period T, corresponding to the characteristic time of the exodus. The time of exodus is determined on the basis of empirical observations over the process of the refugee flow increasing and will be used in the future for the phenomenological model (1)-(4) fine-tuning.

The "convective" term in the equation (1) is responsible for the mutual "carrying along" of refugees – the more people have already decided for leaving the country, the sooner other people attached to them by social or family ties will follow their example. The convective term, given its mathematical nature (the transfer of a vector quantity), should not be interpreted as a kind of "word of mouth" effect, where only the information is distributed in the direction to the potentially loyal or prepared people. On the contrary, it corresponds to the direct, "compulsory" involvement of new "particles" in the refugee flow, when people unambiguously follow the example of their relatives or friends/acquaintances. The "dissipative" term of equation (1) is responsible for the "dispersion" of the refugee flow, when people measure all the consequences of such a step (both economic and psychological) and refuse it, assessing such consequences as being unacceptable. The reason for such a decision can be both infrastructural problems in the country of origin, and problems with a refugees' saturation in the recipient countries. Dissipation in our case corresponds to the decision not to follow the example of the nearest or far environment – that is why the dissipative term is present on the right side of the model equation.

Given the absence of resistance, determined by both economic and infrastructural, and psychological factors, the exodus from the country of origin would occur instantly, that is, the flow of refugees immediately reached the maximum possible value, as specified by the initial conditions in the form (3). The pseudo-time τ required to form a smooth upraising to the maximum levels of the refugee flow U in the system (1)-(2) with initial conditions (3)-(4) is precisely determined by the cumulative (aggregated) influence of all the listed factors. Therefore, as already been mentioned above, to "fine-tune" the phenomenological model (1)-(4) describing a specific case of the refugee flow from a certain country, it is necessary to have statistical data on the characteristic period T, during which the flow of refugees "reached the saturation" and ceased to increase significantly over a long period of time. Defining the constant T based on the empirical data will allow to determine the initial conditions (3)-(4). To put the statistical data to a form convenient for integration over the generalized coordinate x, the magnitude of the registered refugees current value was normalized by some specific value of the stabilized flow which corresponds to the end of the period T, i.e. x varied from 0 to 1.

Considering the abovementioned, to fine-tune the phenomenological model (1)-(4), it is necessary to solve the optimization problem in the following form:

$$\lim_{\tau \to T}[F(U,R) - 1] \to 0 \qquad (6)$$

Problem (6) – minimization of a functional equation, where the function is the solution of a system of nonlinear partial differential equations, is a classic formulation of an ill-posed (inverse) problem of mathematical physics (see (Samarskij & Vabiščevič, 2007) for details), when it is required to find a solution corresponding to its predetermined (known) aggregated characteristics. Such problems are quite widespread in the phenomenological modeling, as well as in the interpretation of observations and empirical data from various fields of science and technology – geophysics, thermal physics, electrochemistry, plasticity and elasticity, image identification, behavioral sciences, psychology, *etc*.

The minimization problem (5) formulation means that such an initial value of the resistance to the refugee flow R=const should be found, which in a result will give the upper limit value of the stabilized number of refugees U_{stat} for a period T corresponding to the empirical observations. That is, according to the observational data, the period during which the flow of refugees has reached the saturation level is estimated, that is, the total number of refugees registered in various countries practically ceased to change, and using this value for T, in the coordinates normalized by U_{stat} magnitude, the optimization problem (6) is solved.

The solution to the problem (6) was carried out using the Wolfram Mathematica cloud service (free basic subscription), which contains powerful tools for optimization, differential equations numerical solution and spatial visualization.

To tune and demonstrate the usability of the model, data on the refugee flow from Ukraine in 2022 (UN Refugee Agency, 2022a), from Syria (2016) (UN Refugee Agency, 2022b), the former Yugoslavia (1999) and Iraq (2003) (UN Refugee Agency, 2022c) were analyzed. As already mentioned, there are no direct analogies between these three scenarios. In addition, unlike Ukraine, Syria and the former Yugoslavia, the number of refugees from Iraq was extremely small compared to the country's population and even the rate of natural emigration. That is, the identification of the phenomenological model was carried out under conditions that differ significantly both qualitatively and quantitatively.

Modeling the hub effect and the infrastructure resistance prevailing. By appropriate setting the initial conditions for $R(x,0)=F(x)$ in (4) it is possible to simulate situations where either the hub effect or the infrastructural resistance to the refugee flow of are prevailing.

If the hub effect prevails, it is assumed that there is a country (region) where refugees are accumulated immediately after crossing the border of the country of origin, and then procced to the other countries (regions). Obviously, Poland serves as a hub for Ukraine, while, for example, in case of Syria, the hub is not just the country of Jordan, but two separate regions of this country, where special refugee camps have been created – *Azraq* and *Zaatari* where an adaptation, training, and primary economic independence providing for the refugees is organized. In the case of the former Yugoslavia, the Benelux countries can be considered as a hub. At the same time, it is difficult to point out any hub for Iraq.

Effect of the "infrastructural resistance" prevailing corresponds to a situation when the very process of the exodus of from a particular country is hindered, either due to transportation problems or due to large-scale hostilities. For example, due to significant damage to the transportation infrastructure and large-scale hostilities, the former Yugoslavia (Serbia most of all) was characterized by the significant infrastructural resistance in 1999, which led to a very limited refugee flow of from this country at the initial stage of hostilities.

It is logical to assume that usually at the early stages of the refugee flow formation the infrastructural resistance will prevail. Afterwards the hub effect will increase due to the refugees' accumulation as already was indicated above during the phenomenological features of the model (1)-(4) outlining.

However, to identify differences in the dynamics of the refugee flow, both the model with the infrastructural resistance prevailing and the hub effect model are of separate theoretical interest. Let us formulate the conditions for F(x) in all these three cases – hub (7), infrastructure (8) and "transitional model" (9):

$$R(x,0) = \text{Heavyside}_\theta(x) = \begin{cases} 0, x < 0 \\ 1, x > 0 \end{cases} \quad (7)$$

$$R(x,0) = 1 - \text{Heavyside}_\theta(x) = \begin{cases} 0, x < 0 \\ 1, x > 0 \end{cases} \quad (8)$$

$$R(x,0) = R_{\min} + (x - 0.5)^2 \quad (9)$$

Once more to describe the initial distribution of resistance to the refugee flow increase the Heaviside piecewise q-function is used, which instantly changes its value from 0 to 1 at τ>0 – conditions take the form (7) and (8). To formulate condition (9), corresponding to the transition from of the infrastructure resistance prevailing to the hub effect, we used the hypothesis that a resistance profile has an augmented minimum $R_{\min}$ when the infrastructural problems were dissolved, and hub resistance did not come into reign.

Let us adjust the models for all three cases of the initial conditions for R (7)-(9). Data for analysis and tuning of models for various countries was obtained from the official website of the UN Refugee Agency. Simulation data (see Fig. 1-3) are presented as surfaces of the "blurring" the jump in the total refugee flow from 0 to the maximum stabilized value over the pseudo-time. Isolines are displayed on the surface, that is, lines of equal values of the vector quantity corresponding to the current value of the refugee flow. The moment when the blurred shock profile ceases to deform in pseudo time τ corresponds to the stationary regime reaching. It is this profile that is compared with empirical observations characterizing the dynamics of the refugee flow from a particular country, and as a result of solving the optimization problem (5), the specifics of the distribution of the resistance to the refugee flow under different regimes are assessed. The features of the theoretical curve and their correspondence to the empirical observations make it possible to identify the mechanism of exodus from a particular country and, accordingly, to understand what the policy towards refugees in each individual case should be utilized.

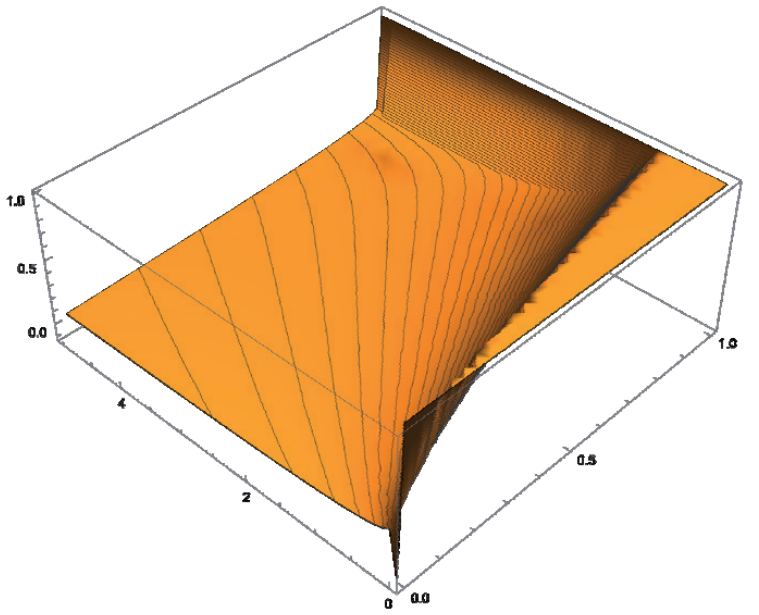

Fig. 1. Surfaces of the jump "blurring" for the infrastructure problems prevailing

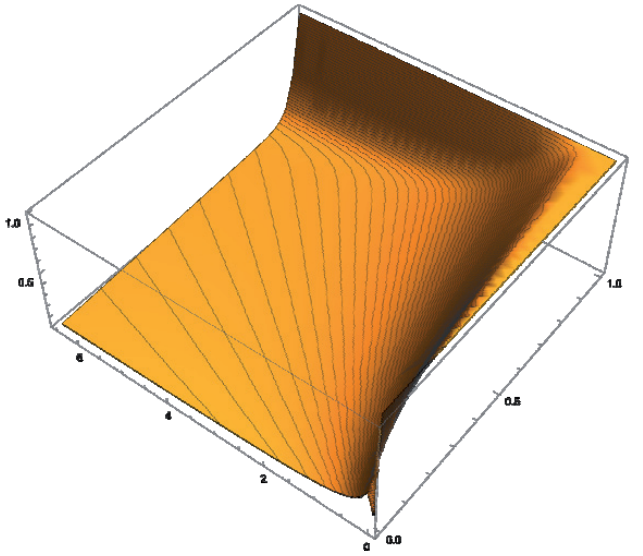

Fig. 2 Surfaces of the jump "blurring" for the hub effect prevailing

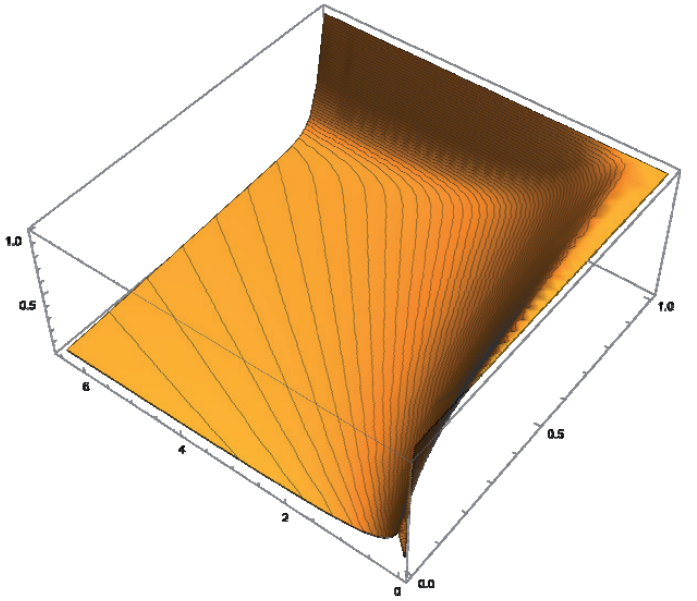

Fig. 3. Surfaces of the jump "blurring" for the transition from the infrastructure problems to hub effect

As already mentioned, the selected countries are characterized by different mechanisms of outcome, while Ukraine takes, in a certain sense, an intermediate position among these mechanisms.

The study of the hub effect allows us to draw the following conclusions:

• reaching the stationary level of refugee flow is exceptionally fast, after which all the flow dynamics could be provided only via changing the external hub "throughput";

• accessing the new levels of the refugee flow could be achieved due to the effects of the emotional and economic

(rational) behavior of refugees replenishing the hub;

• the model makes it possible to determine the moments when changes occur in the nature of the flow of refugees – the transition from the initial stage, when the flow was formed just by the most active citizens to a rapid increase in the flow and reaching the hub "saturation".

In the case when the refugee flow is constrained just by the infrastructural problems in the country of origin, the transition to a stationary regime is delayed. At the same time, the hub ceases to play the role of a balancing element, and the emotional and economic (rational) elements of behavior play a much smaller role compared with regime with the hub effect prevailing. On the contrary, the specific features of the flow are formed under the reigning influence of the problems in the country of origin, and the section of the saturation reaching is "destroyed", that is, further growth is still possible, however, almost all the citizens who, in principle, made such a decision have either left the country or faced insurmountable difficulties in that decision implementing. Processes in the countries hosting the refugees have a considerably smaller impact. The model allows to estimate the strength of the influence of infrastructure problems on the "fullness" of the flow and, accordingly, the delay in reaching the terminating parameters.

The situation of transitional influence, when infrastructural problems play a decisive role at the initial stages of the refugee flow formation, and then the hub effect begins to appear, is closer in nature to the model with the dominance of the hub effect – the flow increases quite quickly and soon the resistance of the hub begins to arise (such a conclusion follows from the shape of the surface which corresponds to the flow profile over the pseudo-time). Thus, in the case of a change in the mechanism of resistance to the refugee flow formation, as in the scenario with the hub effect prevailing, elements of economic (rational) and emotional behavior could play a decisive role. And it is this scenario that is of particular interest to Ukraine, since the refugee flow obeys just this pattern.

The final profile of a "blurred" jump reached by the solution of optimization task (6) for the flow of Ukrainian refugees compared with empirical data is shown on the Fig. 4. Good qualitive correspondence between the theoretical and empirical data is obvious. Although infrastructural problems of the first weeks of exodus are reflected by empirical data.

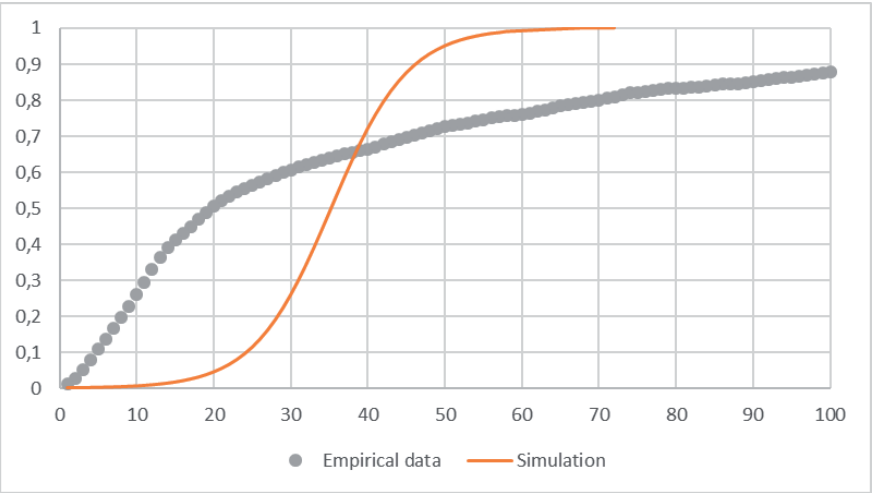

Fig. 4. Nondimensional refugee flow from Ukraine in March-June 2022 (first 100 day of exodus) compared with simulation results

Ensuring the economic self-sufficiency of refugees, as already indicated, has been the basis of the policy of the UN Refugee Agency since 2018 (United Nations, 2018). At the initial stages of this document development, attempts were made to practically apply its foundations in a "discrete version", when separate centers of retraining and reaccommodating were created at refugee camps, as was done, for example, in Jordan, mainly for Syrian refugees. However, in this case the refugees remained approximately in the same cultural environment as in the country of origin. When leaving the camps using clan ties, which are very significant for people from this country, the refugees usually found themselves in a completely different cultural environment.

In such a case, the main factors influencing the economic independence gaining by refugees are labor legislation and the taxation system of the host country, which may have certain differences, even in the EU countries, where legislative systems are extremely unified. For example, for Syrian refugees, the most popular "final destinations" are the Scandinavian countries, for the former Yugoslavia it was Benelux, for Ukraine it is Germany, Spain, Italy, the United Kingdom, while Poland maintaining a dual role – the role of the hub and a popular final destination at the same time (UNHCR, 2022).

In addition, the distribution of employment between the public and private sectors is also quite interesting. A data analysis for Syrian refugees suggests that if only the official employment is considered, then none of the sectors has an advantage. (47% of employment are in the public sector, 53% – in the private). Of course, this proportion does not regard the informal employment volume, considering which the private sector would undoubtedly win. However, it is possible to assess the level of informal employment, especially for people originating from the Middle East, only based on expert judgments which constitutes a topic for the separate study, which is not directly related to our goals and objectives.

The UN Refugee Agency also presents extremely interesting data regarding the probability of employment of refugees from the Middle East (mainly from Syria) in the EU during the first six months of their stay in the destination country in the context of age groups by year. These data provide conclusive evidence of a steady decline in this probability as the economic crisis continues, both in the private and public sectors, although the probability of employment in the private sector remains significantly higher than in the public sector. Again, it should be noted that there is no reliable data on "informal" employment.

At the same time, the probability of the Syrian refugees' employment who have received at least a secondary education is noticeably higher in the countries of the Middle East and North Africa both in the public and private sectors, and since 2016 has shown a remarkable upward trend. It can be assumed that this effect is directly related to the cultural and linguistic proximity of refugees to the recipient country, as well as to the fact that the absolute number of refugees in these countries is much lower, so the labor market "absorbs" new workers more rapidly.

Indirectly, the data referred indicate that the discrete policy of ensuring the refugees' economic independence, which was carried out at the level of international organizations even before 2018, when it was just announced as the dominant one, does not lead to unambiguous results unfortunately.

According to the authors, this may be due to the emotional factors' influence, which, as already mentioned, include cultural closeness, the language knowledge, unity of religion, national customs, *etc*. Modeling the emotional factors' influence on this process is a very exciting task, which also can be solved based on phenomenological modeling, for example, using models of learning with motivation, which convey the nature of the individual's assimilation of the new knowledge, customs, skills, considering motivation, resistance to the "acculturation" process and "scattering"/forgetting. In the most general case, a non-stationary learning model that considers all the above effects has the following form:

$$\frac{dZ}{dt} = \mu \cdot e^{\frac{Z(t)-c}{d-Z(t)}} \cdot \text{Heav}(a - Z(t)) \cdot e^{-(1-\beta)\cdot t} \cdot \left(U - Z(t)\right) \cdot Z(t)^b - \gamma(t)Z(t), \quad (10)$$

where: $Z(t)$ – acculturation's current level, b – the transition speed from the i-th level to the (i+1)-th acculturation level, i – difficulty category of an acculturation; c, d – threshold levels of acculturation, when the motivation moves to a new level, Heav – piecewise Heaviside q-function, a – the acculturation threshold level, where motivation completely disappears ($a \neq c$, d but c could be equal to d), U – the maximum for the acculturation level, that is, in the ideal case $U = 1$, β – the probability that an individual will reach a certain acculturation level, μ – perception coefficient (usually the value μ is supposed being in the range μ>0.7, which is a fact of recognition of satisfactory acculturation results); $g(t)$ – the scattering/forgetting law (model).

The contribution of forced migrants to the economic growth of recipient countries is also an important task that must be addressed along with the determination of the characteristic temporal characteristics of refugees' economic independence gaining. For example, there are already expert assessments that indicate that taxes paid by employed refugees from Ukraine in Poland have practically equalized the costs this state invested for the support of Ukraine in the war (Antezza *et al.,* 2022). However, to verify such a judgment, we run again into the problem of informal employment. In addition, according to the authors, this expert opinion can be based on the total taxes paid by citizens of Ukraine in Poland, which includes those who were officially employed before the start of the Russian invasion (Ratajczak, 2022).

Unfortunately, given the fact that intensive involuntary migration processes from the former Yugoslavia took place in 1997-1999, access to information on the employment dynamics of immigrants from this country is extremely difficult. We can only refer to fragmentary information that in the Benelux countries, individual representatives of Bosnia still enjoy the status of refugees and, accordingly, are subsidized by the state. Accordingly, it can be assumed that the assimilation of this wave of refugees and correspondingly the economic independence gaining turned out to be very difficult for them. However, due to the limited objective information, it is almost impossible to conduct neither a statistical nor phenomenological analysis of this process.

Of course, Ukrainian refugees are culturally much closer to the EU countries, the language barrier for example in Poland is not a serious obstacle. However, both economic (rational) and emotional and psychological factors also influence the processes of their economic independence gaining. Unfortunately, systematic studies of the employment dynamics of Ukrainians in European countries are still at the very early stages of implementation, so there is no reliable statistical information. However, to assess the dynamics of this process and, accordingly, to assess the social services' workload, we can propose to build a model based on the Monte Carlo method. Such a model will allow to directly simulate random (stochastic) contacts between individual refugees, which are accompanied by the information exchange on potential employment, advice and guidance on finding a job, adjusting to local conditions, *etc*. As a result, a peculiar trajectory of an adaptation and the economic independence gaining of a refugee can be built and, accordingly, the "time consumption" of this process can be assessed.

Conclusions. Summing up the analysis of the dynamic processes of the refugee flow formation from the country where hostilities take place, we can draw the following conclusions:

1) a phenomenological model which describes the process of a new participants involvement to the refugee flow, as well as the resistance to that flow formation, was developed based on the system of non-stationary nonlinear equations in partial derivatives, consisting of a one-dimensional equation of convective transport with dissipation (the Burgers equation) and an equation for the resistance distribution,

2) the phenomenological model fine-tuning based on the empirical data utilizing

the solution of an ill-posed problem of mathematical physics made it possible to reproduce all the main theoretical effects of the refugee flow formation and demonstrates good agreement with statistical data relating to different countries, different time periods and different exodus scenarios,

3) three main scenarios for the refugee flow formation were identified and analyzed – the infrastructure problems prevailing, the hub effect and a transitional regime, when infrastructure problems prevail at the initial stages, then the hub effect comes into its reign. The simulated results were compared with the empirical data, based on such a comparison, it was concluded that the phenomenological model developed is suitable in a wide range of the parameters of the refugee flow formation,

4) the analysis of up-to-date statistical information describing various exodus scenarios, carried out for Ukraine, Syria, Iraq and (partially) for the former Yugoslavia, leads to the following conclusions:

a. a stepwise development of the refugee flow is possible in the hub-dominated regime if new hubs would be created, or the existing hub will be freed up from overloading,

b. emotional problems start to play decisive role after hub stop to play a damping role in balancing the refugee flow,

c. hub effect plays decisive role even if infrastructural problems were prevailing at the initial stage of the refugee flow formation.

Unsolved problems & further research directions. As important problems related to the peculiarities of the policy formation regarding the refugee flows management, which remained outside the scope of this study and, accordingly, were not resolved, we mention the following:

1) the theoretical approach development to describe the refugees' behavior in the recipient country at the initial stages of the economic independence gaining. It was preliminary concluded that such an approach could be developed based on the Monte Carlo method application to simulate random behaviors caused by mutual contacts of refugees in the recipient country,

2) development of the refugee's acculturation model (initiation to the language, customs, norms and legislation of the recipient country), as the basis for the simulation of the process of gaining economic independence by refugees. It was preliminary concluded that such a model could be developed based on an equation of a non-stationary learning model with motivation, trust, resistance and "scattering"/forgetting, which would allow to describe the influence of emotional factors on the refugees' behavior and to estimate the period needed for the economic independence gaining after full adaptation to the recipient country norms and requirements.

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SPECIFICS OF GAINING ECONOMIC INDEPENDENCE BY REFUGEES FROM UKRAINE

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The article examines the problems of the emergence and development of the flow of refugees from Ukraine during the first half of 2022 as a complex phenomenon that depends on rational (economic) and irrational (social-psychological) factors. The phenomenological model, created on the basis of the

Burgers' equation, which reproduces the process of the involvement of the new refugees to the flow and the resistance of the environment to the formation of this flow, made it possible to analyze such subtle effects as the existence of a hub country, where the initial accumulation of refugees takes place, followed by redistribution, and the influence of infrastructure problems in the exit country. Transitional regimes from the infrastructural problems prevailing in the country of exit to the predominant influence of the hub-country effects are also considered. It is concluded that the entry to new levels of the refugee flow could be achieved due to the effects of emotional and economic (rational) behavior of refugees replenishing the hub, i.e., a stepwise development of the refugee flow is possible if new hubs would be created, or the existing hub will be freed up from overloading. On the basis of mathematical modeling, it is shown that in the case when the refugee flow is restrained by infrastructural problems in the exodus country, the exit to the stationary regime is delayed. Identification of the proposed model was carried out based on the empirical data on the refugee flow development using the apparatus of incorrect problems of the mathematical physics. A comparison of the dynamic effects of the refugee flow development from Ukraine with similar processes in Syria and Iraq was carried out, which allowed for identification of the zones of influence of infrastructure problems and the hub effect in the refugee flow development. The use of the concept of refugees' economic independence (self-sufficiency), which was developed in 2018 by the Office of the United Nations High Commissioner for Refugees, was proposed as a basis for policy formation in the field of refugee assistance. The consequences of the discrete use of this concept in the case of refugees from Syria are analyzed, and the dynamics of employment opportunities for these refugees in countries with similar and different socio-cultural conditions were compared. A conclusion was made about the fundamental difference in the employment trends in those types of countries. The authors formulated proposals regarding the utilization of the Monte Carlo methods and the learning model for researching the peculiarities of the process of Ukrainian refugees achieving a certain level of economic independence (self-sufficiency), determining the typical time of reaching such a level, obtaining the distribution of probabilities of getting the first job depending on the initial competencies and skills of refuges, their education, experience, and foreign languages mastery.

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