

**ФУНКЦИОНИРОВАНИЕ АВТОНОМНОГО
ФИНАНСОВОГО ЦЕНТРА ПРИ ПОСТОЯННОМ ОБМЕНЕ
КАПИТАЛОМ С НЕОГРАНИЧЕННЫМ ЧИСЛОМ
НЕЗАВИСИМЫХ ТЕРМИНАЛОВ**

Аннотация. Эта статья рассматривает возможность применения математической модели, основанной на рандомизированном уравнении непрерывности, для описания эволюции автономного финансового центра (ФЦ). Данный объект исследуется в приближении открытой системы с неограниченным числом связей (источников и стоков) между ФЦ и окружающей финансовой инфраструктурой при условии того, что каждая связь описывается уравнением непрерывности. Изучение проводится, предполагая, что неограниченное число финансовых связей оправдывает применимость концепции непрерывного фазового пространства как платформы для получаемых соотношений. Данное исследование использует методы математического и функционального анализа, а также результаты эволюционной топологии для интерпретации устанавливаемых взаимосвязей. Найденное решение для энтропии и интегральной эффективности капиталообмена характеризуется встроенным механизмом фазирования, динамической реконфигурацией структуры капиталообмена, регулярным изменением диапазона случайных вариаций, а также возможностью предсказания наиболее вероятных сценариев эволюции. Полученные результаты демонстрируют, что предлагаемая математическая модель может на высоком уровне абстракции описывать процесс эволюции автономного ФЦ.

Ключевые слова. Финансовый центр, рандомизация, финансовая среда, уравнение непрерывности, функционирование.

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**FUNCTIONING OF AUTONOMOUS FINANCIAL CENTER
UNDER PERMANENT BIDIRECTIONAL CAPITAL FLOW
FROM UNLIMITED NUMBER OF TERMINALS**

Abstract. This research examined a mathematical model based on randomized continuity equation that was applied to simulate an evolution of autonomous financial center (FC). The latter was examined in approximation of open system with an infinite number of financial links (sources and sinks) between FC and financial environment where each link was executed by continuity equation. Research is based on the assumption that unlimited number of financial links warrants use of continuous phase space. This study employed methods of mathematical and functional analysis, as well as evolutionary topology to interpret the findings. Found solution for entropy and integral efficiency of the rate of capital exchange is char-

acterized by a built-in phasing, dynamic reconfiguration for structure of capital exchange, regular drift of the range for random variations, as well as property to predict the most probable scenarios of evolution. In general, results demonstrated that suggested mathematical model with a high level of abstraction can describe an evolution process for autonomous *FC*.

Keywords. Continuity equation, financial environment, evolution, financial center, randomization.

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Distinguishing between quantities that are stocks and those that are flows is a quite common in economics, business, accounting, and related fields [1].

In its usual terms, capital inflow refers to the movement of money for different purposes such as investment, trade, or business operations. In natural contrast, capital outflow is a term describing flowing of capital out of (or leaving) a particular entity, like company or national or global economy [2]. Inside of a financial entity, the flow of funds can be in the form of investment capital, capital spending on operations, research and development, and so on [3].

At present days, change of capital actually can be caused by any reasons, including economic, political or any other [4].

Huge diversity of forms for functioning of financial institutions in global economics, ultimately can be thought as a result of interaction between various financial flows with multiple shapes of financial stocks in unlikely economical conditions. In other words, we can assert that above interaction, formally manifesting in establishing of links between financial center (*FC*) and external financial environment (*FE*), is what we can call a functioning (evolution) of *FC*.

Important step in development of financial infrastructure is creation of unmanaged (assumed no direct human involvement) or autonomous *FC*. These *FC* can automatically handle a big volume of money through the high (unlimited) amount of links with independent financial terminals.

Progress of modern economical science and application of its results to global financial infrastructure raises an issue for investigation of conditions for a longtime existence and evolution of autonomous *FC* as a matter of practical and theoretical interest.

Study of *FC* becomes more convenient if we can account results from natural sciences due to the fact that many financial objects demonstrate behavior which is common with natural complex systems. To name just a few, point out to non-linearity response of the key parameters [5], fractal geometry and self-similarity, reproduction near the critical points [6] and others.

In the light of borrowing results from natural disciplines it is important to highlight the mathematical model of self-organization pub-

lished in 1952 by Turing [7] who laid down the grounds for dynamic approach in simulation of complex distributed systems.

Significant contribution to the development of evolution theory of complex systems at inflow of an energy/information from external source was made by Haken [8] thanks to whom the term “synergetic” has become a part of human culture. For natural and artificial systems synergetic is understood as spontaneous forming of structures in the systems far from an equilibrium.

Concept of evolution for complex system as logically relevant consequence of existing natural laws was developed by Oparin in his chemical theory of evolution [9].

Above short introduction prompt to conclusion that successful functioning of *FC* cannot be understood without clear knowledge on the processes of high-level flow-stocks exchange, which in its turn supports all other transformations of stable *FC*.

Obviously that phenomenon of stable functioning for autonomous *FC* requires permanent exchange of capital flows with external *FE*.

In view of the above, a prospective direction for analytical study of common evolution's properties of autonomous *FC* is consideration of its dynamics at big or better unlimited number of independent links with *FE* when specifics of each link is ignored but the fact of contribution of this link to general capital exchange is accounted for sure. While doing that, *FE* can be simulated as a reservoir of unlimited capacity providing lasting capital exchange during lengthy period of time.

Direct support of appropriateness for this approach is provided by theory of Big data [10]. It is known that for forecasting accuracy of mass processes when each single element is the result of random selection, decisive importance belongs not to the limited set of data even from the fairly reliable sources, but as broad as possible scope of data which reflect a comprehensiveness of process variations. At that, obviously that some links will not bring decisive contribution to dynamics of *FC*. Moreover, from an observer's standpoint it can even seem that some links make an anti-evolution contribution. Nevertheless, accounting of all suitable links is indispensable element for construction of *FC*'s models which are able to reflect the real-world processes with acceptable adequacy.

Mathematical formalism

In this section, we will solve unlimited system of continuity equations in assumption that *FC* can be simulated as an open thermodynamic system with permanent access to the unlimited financial reservoir. We will believe that *FC* operates with the high volume of financial operations which allows to consider result of each single operation as an infinitesimal one. As a result, we can apply the continuous approach and suitable methods of mathematical analysis.

So, let process of capital exchange in each single operation in its differential form be represented as a continuity (CE) equation. Going to the set of above operations, we can write down the volume of such set as

$$I = I_1, I_2, \dots, I_i, \dots, \quad (1)$$

where i -th element

$$I_i : \left[\frac{\partial \varepsilon_i}{\partial t} = -\text{Div } \mathbf{J}_i \right] \quad (2)$$

\mathbf{J}_i — flux of capital, ε_i — capital density, t — time, and Div — divergence operator.

At unlimited number of links, (2) can be transformed to randomized continuity equation

$$\frac{dU}{Q} = -\frac{dJ}{J} x \quad (3)$$

[11], which allows finding of a closed-form solution, where $x = \cos \varphi$, φ is angle between direction of instantaneous change J and unit normal, $dU = \varepsilon \cdot dV$, $Q = J \cdot dS \cdot dt$. Essentially, such theoretical construction is compatible in full with existing physical paradigms.

From (3), considering y and x independent and taking Riemann integral on dy , we obtain

$$\Upsilon = -\int x \int \frac{dy}{y} = -\int_D \delta \Upsilon(x, y), \quad (4)$$

where $y = J/J_0$, $J_0 > 0$ is normalizing constant, $D \subseteq \mathbf{R}^2$ is the phase space for all possible states of $\delta \Upsilon$.

To rid of random quantities, integrate one more time on dy , so we have

$$\Upsilon = \iint \frac{dU}{Q} = -\iint \frac{dy}{y} x \quad (5)$$

and, finally

$$\Upsilon(y) = y - y \ln y \quad (6)$$

shown in Fig. 1.

Appropriate solution for entropy S

$$\Delta S = \ln |\ln y| + H_x \quad (7)$$

shown in Fig. 2, where H_x is entropy probability distribution for x on the compact support $[-1, 1]$

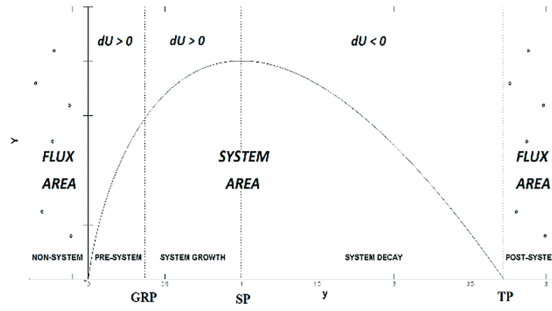


Fig. 1. Dependence of integral efficiency Y on rate of capital exchange between FC and its FE y .

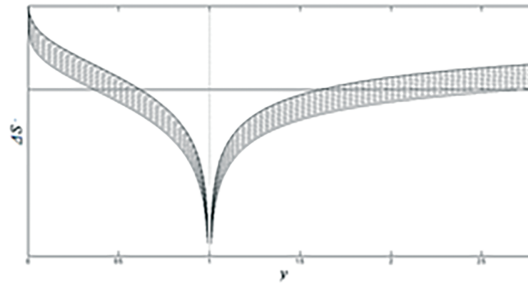


Fig. 2. Dependence of entropy S on rate of capital exchange y . Shown y -roots of entropy S match the first and second harmonic of the discrete spectrum for evolving FC.

$$H_x = - \int_{-1}^1 g(x) \ln(g(x)) dx \quad (8)$$

and $g(x)$ – probability density for random x .

Since H_x is limited

$$H_{x \min} \leq S - \ln | \ln y | \leq H_{x \max} \quad (9)$$

it leads to the limited range for $y - S$ variations (Fig. 2).

Conveniently, minimum dissipation fits $H_x = 0$. Then, the pair of the outmost entropy curves is $y = \exp(\pm \exp(S))$.

To calculate the innermost border curves, we should know value of $H_{x \max}$ which corresponds to the state of the highest disorder possible when a random variate x has uniform distribution [12], which in this model means that density $g(x) = 1/2$, then $H_{x \max} = \ln 2$.

Now, based on found entropy roots, we may write

$$\lim_{H_x \rightarrow \min} S_0 = \exp(\pm 1) \quad (10.a)$$

$$\lim_{H_s \rightarrow \max} S_0 = \exp(\pm \frac{1}{2}) \quad (10.6)$$

where symbol S_0 means roots for entropy S .

It is important to note that y -roots of entropy are equal to the first and second harmonic of discrete spectrum evolving FC .

Singularity of solution at point $y = 1/e$

Our research showed that in the range $0 \leq y \leq 1/e$ the outputs favoring to flux $y = y_{in}$ inward FC are more probable than to flux $y = y_{out}$ outward FC , whereas beyond point $y = 1/e$ in the range $1/e \leq y \leq e$ situation changes is opposite, here e is Euler number [11]. The same scenario happens with the entropy rate dS/dy , which grows at $y < 1/e$ and decreases at $y > 1/e$. Similar behavior exists for the amplitude of fluctuations of dS/dy either, which demonstrates maximum at $y = 1/e$. Finally, the amplitude of the x -fluctuations starts to decrease at $y = 1/e$, and $y = 1/e$ is one of the roots of entropy (7).

Discreteness of evolution spectrum

From (6), to meet the suitable boundary conditions should hold

$$1 = \pm n \ln y_n \quad (11)$$

so, at $|\ln y| \leq 1$, i.e. in the range $[1/e, e]$

$$y_n = \exp[\pm \frac{1}{n}]. \quad (12)$$

So, the y -points (12) are the nodes of the discrete spectrum and the point $y = 1/e$ is the first node, where spectrum mode of evolution changes from continuous to discrete.

As we saw above, limitation imposed on the range $[0, e]$ mathematically leads to seizing of solution within the range $[1/e, e]$. Ultimate reason of that is quantization of unit interval $[0, 1]$ occurring at evolution of FC as below

$$\mathcal{G}(n) = \frac{1 - |\ln y_n|}{|\ln y_n|} = n. \quad (13)$$

Connection between algebraic and topological parameters of the model

It is possible to show that algebraic and topological parameters in our model are linked through the factor k

$$\kappa = 1 - \text{sign}(\ln y) |\ln y|, \quad (14)$$

which is an eigenvector for interface operator (6), where *sign* is the sign function [15]. Above provides grounds for direct applying of relationships originally developed in evolutionary geometry [16] to capital ratios above.

Now, (7) can be rewritten as

$$\Delta S_n = \ln \ln y + nH_x \quad (15)$$

Then, the least probable (most slow) scenario of evolution for *FC* happens at $n > 2$ и negative change $\Delta S_n < 0$. So, evolutionary scenarios without positive phase $\Delta S_n > 0$ at all, are the less probable at the same time. It is worth to note that above said does not mean that harmonics with $n > 2$ are completely impossible. It only means that the true evolutionary scenario is more probable for ΔS_n laying within the interval for *y*-roots $[e^{-q}, e^q]$, where $1/2 \leq q \leq 1$.

Also, from (15) follows that maximum ΔS_n (maximum dissipation) is at maximum H_x (maximum number of loops) and $n = 1$ (fits to the first harmonic of discrete spectrum y_l at *FC* evolution). Then, according to principle of maximum entropy production [17], such scenario fits to the most probable and the fastest path of evolution.

So, the most probable (maximum randomness) evolutionary scenario assumes realization of evolution process within the *y*-range limited by the roots of first harmonic $y_l [1/e, e]$. In the contrast, the least probable (minimum randomness) scenario assumes realization of evolution process within the *y*-range limited by the roots of second harmonic $y_2 [e^{-1/2}, e^{1/2}]$. The remaining scenarios take the niche in between above two by decreasing probability of realization going from y_l to y_2 .

Evolutionary topology of capital exchange

As is shown in [11], function $\gamma(y)$ is the generalized characteristics of an average efficiency for the process of transportation through system interface at given rate of capital exchange *y*. Then, area of the so-called *Capital-Exchange Forms* (*CEF*) is the weighted efficiency for an interaction between *FC* and external environment [16].

Based on results [11], there is relation between areas of *CEF*

$$\left(\frac{2S_n^T}{S_n^C}\right)^p = \gamma(k) \left(\frac{S_n^F}{2S_n^T}\right)^p = \tau, \quad (16)$$

where $\gamma(k) = (4/k^2)^p$, $p = \pm 1$, $n = 1, 2, \dots$, S^T (area of transfer triangle), S^C (area of core triangle) and S^F (area of full triangle) $= 2S^T + S^C$ (Fig.3). Note that S^w (area of triangle *ABC*) $= S^C + S^T$.

From (16) follows that

$$\eta^2 + 2\eta - k^2 = 0, \quad (17)$$

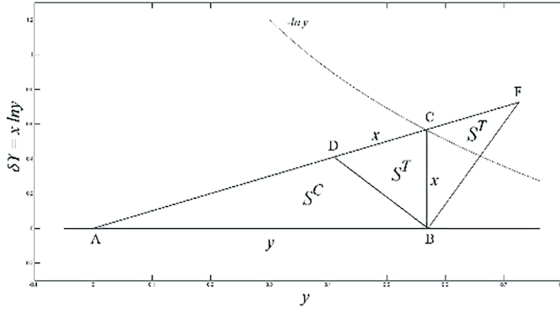


Fig. 3. Capital-Exchange Forms of evolving FC. In the plot, the following areas are shown - S^T (transfer triangle), S^C (core triangle) and S^F (full triangle) = $2S^T + S^C$.

where

$$S^C (S'' \pm S^T) = (kS^T)^2 \quad (18)$$

which provides breakdown for CEF at fixed k .

As such, (17) deals with the *predetermination* in the structure for capital exchange (fine structure of spectral harmonic) as to survive, CEF-mode should have maximum ratio η . Hence, evolution manifests by a mixture of the quickly depressing modes at $y \neq y_n$ which do not have maximum ratio η and the stable modes at $y = y_n$ when η is of maximum. In this sense, we could say on existence of FC evolution infrastructure. Of course, use of this infrastructure is subject of attainment of suitable capital exchange rate y which is not assured.

Also, based on [11], at $y = 1/e$, ratio $\tau = \varphi$ (16), where φ is a golden ratio, so an instantaneous internal structure of an capital exchange in the FC achieves the state of dynamic balance [18]. That is why we call point $y = 1/e$ as *Golden Ratio Point* (GRP).

Built-in phasing of evolution

It is clear that GRP separates two dissimilar y -ranges when evolving FC makes qualitative transition from one operational mode to another. For convenience, we can call these two ranges as *agenesis* ($y < GRP$) and *genesis* ($y > GRP$). It is worth to note that genesis is different, first of all, by emergence of new qualities in functioning of FC that were not presented before. It is quite aligned with [19] where is stressed that emergence of quality difference for evolving entity is identifiable not by the new parts but novelty of operation.

Also, GRP is not unique. Other nodes of the discrete spectrum can feature the phase transition properties either [11].

So, evolution of FC could be considered as succession of the qualitative jumps between unlimited counted number of stable spectral harmonics. In this sense, we may say about a phasing of FC evolution.

Dynamic decomposition of structure for capital exchange

Based on (16), it is possible to obtain the following ratio:

$$S^C (S^{tr} \pm S^T) = (kS^T)^2 \quad (19)$$

It means that S^C is the quantity which keeps its value for each specific node n and change of this value will alter its state (node n). However, S^T is the different kind of quantity, which supports trading of capital, it is not related to the node. Coupling between S^C and S^T optimizes performance capital exchange of FC during its evolution.

Capital covariant reduplication

As fairly noted in [20], a quantitative understanding of evolution would flesh out the balance between evolvability and robustness (S^T and S^C in this model). Evolution of capital exchange in FC is governed by η (17). Therefore, to evolve, FC should support regular change of random S^T . In this sense, during evolution, S^T should experience regular alternations either. In analogy to phenomenon of covariant reduplication [21], it can be called as a covariant reduplication of capital exchange.

Individual and collective CEF

We investigated vicinity of $y = GRP$ and discovered a number of dramatic changes in behavior of evolution parameters as was highlighted earlier. In this point, FC experiences deep internal reconstruction which manifests itself through appearance of new quality features. In this sense, genesis logically and timely follows agensis. Under this angle, it appears that a major essence of agensis stage is to supply capital (continuous spectrum of \mathcal{Y}) and prehistory ($\delta\mathcal{Y}$ loops) in an amount sufficient to support the more complicate (discrete) mode for operation of FC at the stage of genesis. We demonstrated that GRP has a bunch of breaking features and, in our opinion, deserves to be thought as a hallmark separating two very dissimilar phases in FC evolution.

Since at agensis FC encounters strong influence of incoming capital flow y_{in} , maintenance of its structure requires the highly efficient capital-saving mechanisms (factor S^C) leaving significantly less capital on the variability endeavors (factor S^T), *i. e.* holding $S^C \gg S^T$. Further, out coming flux y_{out} gradually becomes bigger, finally reaching some parity with y_{in} in vicinity of GRP which is compliant with the state of dynamic balance. In this sense, effective management of outward capital streaming is regarded one of the main merits of orderly advanced FC .

Staying compliant with above said on eminent segregation between two stages of *FC* evolution, we think that it would be reasonable and physically warranted to assume existence in different evolutionary stages the different kind of a capital utilization mode. Namely, the *collective* mode in a genesis and the *individual* one in genesis.

Above assertion acquires more sense if we acknowledge that collectivity in capital organization is relied on the low accuracy of copying between adjacent forms because of the infinitesimal y -difference between them. Then, it looks like that *collective* form is the only acceptable solution to evolve in an a genesis. On the other hand, the higher accuracy of copying in genesis naturally matches the finite y -distance between the separated *CEF*.

We think that an evolution meaning of function Y could be understood in the terms of some *accumulative* or *collective memory*. Thinking this way, we mean that *collective memory*, like Y , “writes” and “keeps” all the attempts, successful and unsuccessful ones. With each consecutive even unsuccessful attempt, operation of *FC* becomes more and more ready to contribute to fastening of some preferences thereby moving it to the next level of complexity.

Especially stress that on the one hand, the most stable *CEF* (spectral modes) should have the maximum ratio S^T/S^C . On the other hand, the highest accuracy of copying (S^C) between the predecessor and the successor *CEF* is achieved at the y -values matching the eigen values of capital exchange y_n . So, emerged *CEF* is a result of compromise and balance between necessity of the highest accuracy of coping and the highest variability.

Following this way, it is possible to comment out an existence of some distance (in y -terms) from the point of stationarity (*SP*) as essential requirement for

FC functioning. The maximum distance is $SP - GRP$ (at $y < I$) and TP (terminal point $y = e$) – SP (at $y > I$), but the minimum one could not be defined exactly.

Existence of such minimum stems from the fact that staying around *SP*, evolutionary states of *FC* lack its unique identity. It happens due to decreasing of separating distance between individual *CEF* along y (separation distance approaching 0 at $n \rightarrow \infty$) still keeping the high accuracy of copying. All this makes *individual CEF* practically indiscernible.

Final remarks

In this report, we presented analytical model for a capital exchange evolution of *FC* based on the infinite number of the financial links with a *FE*. We knowingly established an infinite number of financial links, *i. e.* financial sources and sinks considering that such condition is critical

in evolution process. We did it because, in our opinion, the number of financial connections, all sorts of different nature between an object which potentially could become less or more advanced *FC* and an external financial world is what makes evolving financial entities different from the stagnating ones. Hence, we think that for evolving entities the number of such links should be incommensurably higher than for the non-evolving ones. That is why we replaced classic *CE* with the system (1) and, finally, with (3).

Doing this, we demonstrated possible way how self-organization and evolution can happen in as a consequence of the flow of capital through an interface of *FC*.

Our approach is being essentially built around interface function Y . We found that function Y can be considered as a marker in a lifetime cycle for capital development of *FC*. Based on above, we exhibited how multiple changes in capital flow direction may activate evolution potential of *FC*.

An evolution ability of discussed model, in particular, is based on the probabilistic anisotropy of *FC* interface for capital fluxes y_{in} and y_{out} . Observe that it looks identical to the results [22] where it was established macroscopic compliance with the second law of thermodynamic with the reverse and forward transition probabilities.

Our results support position [8; 13; 23] that complicate system's native ability to adapt to changes in environment goes through suppressing big fluctuations around critical points (phase transition points $y = y_n$ in this model) and dissipating abundant capital (y_{out} in this model) and reflect the well-known property of a system to operate close to the phase transition point keeping away from equilibrium [14].

So, the driving force of development creates general probabilistic background which makes complexification and evolution at some conditions unavoidable.

Author [13] comes to close conclusion stating that the adaptation feature of systems "...may be embedded more deeply in the thermodynamics of complex systems".

Also, highlight here that all distinguishing differences of a genesis compared agensis, listed above can come only altogether, as one united ensemble. If we take off any of these features, it immediately breaks a whole pattern of this stage. Exactly the same should be said for the stage of agensis.

Finally, of importance is that the formalism developed in this paper is supplemented and explained by relations coming from evolutionary topology [15].

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