# A Structural Model of Exchange Rate Dynamics

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**Abstract.** The concept of formation of the equilibrium exchange rate on the conversion market was developed, taking into account foreign trade, capital flows and other components of the balance of payments. As the main determinants of theoretical-structural model of the dynamics of the exchange rate equal countries are used, in the terms of trade, capital mobility, cumulative releases, internal and external prices. The result is a new final structural dependence of the dynamics of the exchange rate on the key macroeconomic determinants. The results obtained are applied to the study of the concept of purchasing power parity that allowed to justify theoretically — from positions of macroeconomic approach — a fundamental mismatch between the value of the exchange rates and the theory of purchasing power parity.

**Аннотация.** Разработана концепция формирования равновесного валютного курса на конверсионном рынке, учитывающая внешнеторговые операции, движение капитала и иные составляющие платежного баланса. В качестве основных детерминант теоретико-структурной модели динамики валютного курса равноправных стран используются условия торговли, элиминирующиеся в процессе рассмотрения модели, факторы мобильности капитала, совокупные выпуски, внутренние и внешние цены. В результате получена новая итоговая структурная зависимость динамики валютного курса от ключевых макроэкономических детерминант. Полученные результаты применяются к исследованию концепции паритета покупательной способности, что позволило теоретически с позиций макроэкономического подхода обосновать фундаментальное несоответствие значений валютных курсов теории паритета покупательной способности.

**Keywords:** Exchange rate, modeling, balance of payments, trading conditions, purchasing power parity.

## CONCEPTUAL APPROACH TO THE ESTIMATION OF THE EQUILIBRIUM EXCHANGE RATE

In economic literature there is a steady interest to the problems of forming the fundamental equilibrium value of the exchange rates. Here we support the point of view of Engel, Mark and West (2007, revised in 2011): "Standard models of exchange rates, based on macroeconomic variables such as prices, interest rates, output, etc., are thought by many researchers to have failed empirically. We present evidence to the contrary".

The need for a thorough analysis of the behavior of macroeconomic aggregates, their interdependence is complicated by the effects of devaluation on the global level consideration. Conducting internal macroeconomic policy often leads to improvement of the situation at the expense of the environment. The negative effects of devaluations lead to the issue of "fair" rates of exchange, which must be resolved solely with regard to fundamental economic factors that are aimed at removing growing in international trade voltage. And here perhaps the most important problem is the coordination between participants, their combined vision system, the degree of agreement on the activities, as well as mutual accountability. In this article we study significant trends observed in the world economy, based on the class of models of the exchange rate dynamics of two equal countries-suppliers developed by the author (Kuzmin, 1999, 2010, 2012).

Conceptually to study the dynamics of exchange rates with varying degrees of floating we determine the exchange rate $e$ as the average weighted on volumes of foreign currency values $N$ conducted market transactions $e_i, i \in (1, N)$ for a certain period of time:

$$e \equiv \sum_{i=1}^{N} \frac{D_i}{\sum_{j=1}^{N} D_j} \times e_i, \qquad (1)$$

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where, $e_i, D_i, R_i$ are, respectively, the exchange rate, the amount in foreign currency, the amount in the domestic currency of the *i-th* transaction, i.e.

$e_i D_i = R_i \cdot$ or $e_i = R_i / D_i$.

Thus, from (1) can be obtained by summing over *i*:

$$e = \sum_{i=1}^{N} \frac{D_i}{\sum_{j=1}^{N} D_j} \times \frac{R_i}{D_i} = \sum_{i=1}^{N} R_i \Big/ \sum_{j=1}^{N} D_j .$$

Here in the formula we can take into account the funds that came to the currency market:

- on the supply side of the national currency for transactions of current account operations (hereinafter in formula (2) variables with top index CA) and capital movement (variables with top index K),
- on the supply side of foreign currency for the same purposes, including foreign exchange receipts from exports,
- in the interventionist actions of monetary authorities to regulate the exchange rate (variables with top index CB).

Thus, the main result of a conceptual level shows that the exchange rate is equal to the aggregate amount of funds in domestic currency, divided by the total amount of funds in foreign currencies traded in the currency market during this period. In the final formula, disaggregated flows on accounts of the balance of payments can be represented as:

$$e = \frac{\sum R^{CA} + \sum R^{K} + \sum R^{CB}}{\sum D^{CA} + \sum D^{K} + \sum D^{CB}} . \qquad (2)$$

## THE BEHAVIOR OF INVESTORS AND TRADING CONDITIONS IN THE MODEL OF EXCHANGE RATE DYNAMICS

In this model, the world presents two countries that trade with each other, in accordance with their international competitive positions (trading conditions), expressed by the value of the real exchange rate. There are also equal bilateral relations of the two countries-contractors and joint actions of monetary authorities to maintain stability of the exchange rate at the desired level. The variant of "one small country and the rest of the world" is preferable to model according to the methodology set out in the articles by the author (Kuzmin, 2011, 2014).

Thus, the flow of funds in the formula (2) are presented symmetrically in relation to each other export-import flows of partners and capital flows: I*=E, E*=I, $K^{*-} = K^{+}, K^{*+} = K^{-}$.[1] In the framework of the introduced notations $\sum R_i^K = K^{-}, \sum D^K = K^{+}$ — accordingly, the amount of funds outflow (demand in national currency for foreign currency) and inflows of foreign currency supply on the capital account, and

$\sum R_i^{CA} = I \quad \sum D_i^{CA} = E$ — accordingly, the demand in national currency for foreign currency from imports and supply of foreign currency from exports.

In the result the exchange rate is represented in the form

$$e_t = (I_t + K^{-}) \Big/ (E_t + K^{+}) = (E_t^* + K^{*+}) \Big/ (E_t + K^{+}) = (E_t^* + K^{*+}) \Big/ (I^*_t + K^{*-}) = 1 \Big/ e_t^* ,$$

with perfect symmetry determination of exchange rates of these two countries-suppliers.

[1] Asterisk here and below marks the variables related to the opposite side.

An important place in the study of the factors movement of the exchange rate is the analysis of the impact of relative international competitive advantages in global trade flows and, indirectly through the creation of a favorable investment climate, on capital flows. Structural changes in the world, the presence of real imbalances have a significant impact on the mobility of the exchange rate, and their deviations from the equilibrium values and the emergence of these mega world trade factors are creating competitive advantages for residents of one country over the other. This is due to the mechanisms of change in real exchange rates, which are based on the decisions of the agents at the micro level, thus affecting global trade flows (and indirectly through the creation of a favorable investment climate on the capital flows). Relative prices and costs are important factors in the terms of trade and international benefits, by which the real exchange rate has a tendency to return to its equilibrium value.

Also, increasing demand for national currency, supplemented by a decrease in the supply of foreign currency, is caused by the following real and psychological factors:

- fears of investors about raising interest rates to curb the economy from overheating,
- improval of the investment climate by increasing economic growth and inflow of portfolio and direct investment,
- perceived and anticipated effects of import substitution.

All these factors are related to the capital account. We would accept the hypothesis that the magnitude of capital inflows is a function, increasing in real total product (international investors and speculators want to buy its part at their prices for aforementioned reasons) and in terms of trade, represented by the value of the real exchange rate $e^R_{t-1} = e_{t-1} P^*_{t-1} / P_{t-1}$. The last explanation lies in the fact that the fall of the national currency (respectively the increase in the exchange rate) improves the investment conditions for non-residents.

The following dependence is observed:

$$K_t^+ = k_{K^+} P_t^* \sqrt[3]{(Q_{t-1}{}^2 Q_t)^{\theta}} e^R_{t-1}, \tag{3}$$

where $Q_t$ - cumulative real issue (for example, real GDP), $P_t$ — total price levels and indexes *t, t-1* indicate, respectively, the beginning and the end of the period.

The function of the outflow of capital allocated for investment and speculative purposes is defined symmetrically:

$$K_t^- = k_{K^-} P_t \sqrt[3]{(Q^*_{t-1}{}^2 Q^*_t)^{\rho}} e^{*R}_{t-1}. \tag{4}$$

On construction $\theta$ and $\rho$ can serve as a measure of international capital mobility — their value corresponds to a greater mobility of the relevant cross-country flows.

Also the volume of exchange, supplied to the domestic market, is determined by the volume of exports, which depends on the real terms of trade, and is determined by the decisions of producers-exporters in time *t-1*:

$$E_t = P^*_t k_E \sqrt[3]{(Q_{t-1}{}^2 Q_t)} e^R_{t-1} = P^*_t k_E \sqrt[3]{(Q_{t-1}{}^2 Q_t)} e_{t-1} P^*_{t-1} / P_{t-1}. \tag{5}$$

Part $k_E \sqrt[3]{(Q_{t-1}{}^2 Q_t)}$ reflects the fact that the export is a part of total output (for the reasons similarly expressed by Kuzmin (1999)).

Accordingly, the demand for the local currency is symmetrically determined by the decisions of producers and importers (recall that the importing country is exporting its contractor):

$$I_t = E^*_t = P_t k_I \sqrt[3]{(Q^*_{t-1}{}^2 Q^*_t)} e^{*R}_{t-1} = P_t k_I \sqrt[3]{(Q^*_{t-1}{}^2 Q^*_t)} e^*_{t-1} P_{t-1} / P^*_{t-1}. \tag{6}$$

Many authors in the analysis of the exchange rate distinguish the terms of trade, reflected in the effectiveness of foreign trade operations, as one of the determining factors. Structurally similar dependencies

were generally confirmed by Bahmani-Oskoee and Goswami (2004), who focused on research of export-import operations in the world trade.

The model of the exchange rate of the ruble (Kuzmin, 2011) is also substantiated and proved on the statistical series of exports and imports of Russia in 1997–1999 and 2007–2009 and the use of agents at the micro level as the main determinants of foreign trade transactions in terms of trade, expressed and adjusted for price levels of the nominal exchange rate.

Interesting research (Caramazza, 1993) showed that investors' expectations of changes in the parity DEM/FRF during 1987–91 can be explained largely by some fundamental macrovariables, including the relative inflation differential and the terms of trade. In (Bartolini, 1993) similarly a link is found between trade advantages and market expectations of devaluation in 1987–1993. Also a link was found between the expected devaluation and that CPI is an indicator of the international advantages.

In fact at this stage there is a conceptual difference in the assessment of threads on import operations and the subsequent results compared to the modeling methodology "one small country and the rest of the world", where the import is not dependent on the actual conditions of trade expressed by the value of the real exchange rate. Symmetry and equality are making adjustments, and the future will permit analysis of a number of important and interesting effects in the behavior of the real and nominal bilateral exchange rates, balance of the payment balance and formation of an international competitive advantage.

Substituting in (2) formulas (3), (4), (5), (6) and taking into account the symmetry of the real bilateral exchange rate $e^{R}_{t-1} = e_{t-1} P^{*}_{t-1} \big/ P_{t-1} = 1 \big/ e^{*R}_{t-1}$ :

$$e_t = \frac{k_I P_t \sqrt[3]{Q^{*\,2}_{t-1} Q^{*}_{t}}\, e^{*R}_{t-1} + k_{K^-} P_t \sqrt[3]{(Q^{*\,2}_{t-1} Q^{*}_{t-1})^{\rho}}\, e^{*R}_{t-1}}{P^{*}_t k_E \sqrt[3]{Q^{\,2}_{t-1} Q_t}\, e^{R}_{t-1} + P^{*}_t k_{K^+} \sqrt[3]{(Q^{\,2}_{t-1} Q_t)^{\theta}}\, e^{R}_{t-1}} = \frac{P_t \sqrt[3]{(Q^{*\,2}_{t-1} Q^{*}_{t})^{\rho}}\,(k_I \sqrt[3]{(Q^{*\,2}_{t-1} Q^{*}_{t})^{1-\rho}} + k_{K^-})}{P^{*}_t e^{\,2}_{t-1} \left( P^{*}_{t-1} \big/ P_{t-1} \right)^2 \sqrt[3]{(Q^{\,2}_{t-1} Q_t)^{\theta}}\,(k_E \sqrt[3]{(Q^{\,2}_{t-1} Q_t)^{1-\theta}} + k_{K^+})}, \quad (7)$$

$\theta \geq 0, \rho \geq 0.$

Now, using the properties $\rho, \theta >> 0$ and assuming a constant due to the significantly greater stability dynamics of the average member of the species $\sqrt[3]{(Q^{\,2}_{t-1} Q_t)^{1-\theta}}$ in comparison with the mobility of external and internal prices,

$$\frac{(k_I \sqrt[3]{(Q^{*\,2}_{t-1} Q^{*}_{t})^{1-\rho}} + k_{K^-})}{(k_E \sqrt[3]{(Q^{\,2}_{t-1} Q_t)^{1-\theta}} + k_{K^+})} = (k^{/})^3 = const,$$

let's rewrite (7) in the form

$$e_t (e_{t-1})^2 = \frac{k^{/} P_t}{P^{*}_t} \frac{Q^{*\rho/3}_t}{Q^{\theta/3}_t} \left( \frac{k' P_{t-1}}{P^{*}_{t-1}} \frac{Q^{*\rho/3}_{t-1}}{Q^{\theta/3}_{t-1}} \right)^2. \quad (8)$$

Intertemporary separation of variables makes it in the final formula:

$$e(t, Q(t), P(t), P^{*}(t), Q^{*}(t)) = e_t = k^{/} \frac{P_t}{P^{*}_t} \frac{Q^{*\rho/3}_t}{Q^{\theta/3}_t}. \quad (9)$$

You can now specify the exogenous variables in the model. In (9) there are the price levels *P, P** and comprehensive products *Q, Q** in the countries of this bilateral exchange rate. Other important determinants of the behavior of the exchange rate are indicators of capital flows between countries, certain values $\rho, \theta$.

In the model-building process other factors (variables import and export, as well as other components of the balance of payment, and terms of trade) were eliminated.

Generally speaking, the formula (9) is true if the assumption about the equality of the coefficient *k"* is constant. This problem can be circumvented by using the other functions of the linear form (as shown by the author (Kuzmin, 2010)). Under other equal $(P_t^* = const, Q_t = const, Q_t^* = const)$ exchange rate is directly linked to changes in domestic prices. That is, any actions of the authorities to increase the money supply will lead to an outflow of funds on the foreign exchange market and proportional increase of the rate. On the other hand, if the exchange rate is managed by the Central Bank it is appropriate to change it in direct accordance with the dynamics of domestic prices. Especially it comes to the regime of regulated (called "dirty") floating. You can also see that the currency rate rises with increasing foreign prices, reflecting the symmetry of the situation.

Here it is important to note that one of the most important factors that determine the medium and long term movement of the nominal exchange rate is the inflation differential between countries. This is confirmed by the work (Lane, 1999), dynamically $\frac{P_t}{P_t^*}$, or in logarithms $D_\pi = \pi - \pi^*$ in definitions of the author, who examined the econometric model on quite representative data of 1974–1992, including the OECD countries, taking into account the behavior of the real exchange rate, defined as $e^R = e\left(P^* \diagup P\right)$.

Checking of the dependency of type (9) within the scope of verification of monetary models was repeatedly carried out with success. On the basis of methods of assessment maximum likelihood approach for determining the co-integration vector time series of Johansen-Juselius (Chouldhry, Lawler, 1997), based on data on exchange rates of the Canadian dollar against the currencies of major contractors, and Moersch and Nautz, (2001), based on quarterly data at the rate of USD/DEM 1983–1996, confirmed the source of the dependence of the type (9).

In the model $\theta$ and $\rho$ characterize the degree of physical supply of capital. These indices are responsible for huge changes in market exchange rates that occur due to explosive changes in the capital account, expressed in speculative attack on the currency. This is largely caused by the instability of the political situation, panic moods of investors, etc.— a situation typical for post-crisis Russia, when it devalued its national currency in 1998–99 more than four times, (that is comparable with the results of devaluations in Indonesia (73,8%) and South Korea (48%)), as well as serious and sufficiently rapid devaluation of September 2008 — February 2009.

## PURCHASING POWER PARITY AND EQUILIBRIUM DYNAMICS OF THE EXCHANGE RATE

In the long term, however, it is changing in fundamental ways from the linear expressed by the formula (9). This is due to the change in the coefficient *k'*, which ceases to be a constant. It is easy to notice in $\sqrt[3]{\frac{(k_I \sqrt[3]{(Q_{t-1}^{*\,2} Q_t^*)^{1-\rho}} + k_{K^-})}{(k_E \sqrt[3]{(Q_{t-1}^2 Q_t)^{1-\theta}} + k_{K^+})}} = k'$, that uneven development of economies in the long run will result in changes to k', the greater the larger the difference in growth rates.

Stable high rates of growth, improving investment climate, inflow of capital into the country, credibility of national economic policy in the long term lead to appreciation of the nominal exchange rate (hence, the real exchange rate), which can be observed in the world economy on the example of the overvaluation of currencies of industrial countries against the developing. This effect is examined below.

Comparison of the results of the behavior of the exchange rate, expressed by the formula (9) and PPP-rate $e^{PPP} = P \diagup P^*$ leads to important conclusions: even in case of a zero trade balance and at the same time

zero balance capital — with a stable form of total releases $Q_t^{*1/3} \Big/ Q_t^{1/3} = const$ — equality of results will be achieved only if *k'=1* (that is, the equality of the coefficients associated with the coefficients of elasticity of exports and imports $k_{E^*} = k_E = k_I$ in total production), which generally speaking is not guaranteed. In the more general case when taking into account capital movement impossibility of *k'=1* due to non-uniformity of development (size and growth rate of total output), a mismatch behavior of the nominal exchange rate of the theory of PPP in the long term and in the medium term is guaranteed.

The above concerns not only the absolute, but relative version of PPP-rate. This concept, embodied in the works of G. Kassel, changes the form of dynamics $e^{PPP} = k P_t \Big/ P_t^*$, but with no conclusions. Also important here is the dynamic behavior of indicator $\sqrt[3]{\dfrac{(k_I \sqrt[3]{(Q_{t-1}^{*\,2} Q_t^*)^{1-\rho}} + k_{K^-})}{(k_E \sqrt[3]{(Q_{t-1}^{2} Q_t)^{1-\theta}} + k_{K^+})}} = k^{/}$, associated with the initial equilibrium, and the differential in rates of development $\dfrac{Q_t^{*\rho(t)/3}}{Q_t^{\theta(t)/3}}$.

Despite this, a significant number of economic models assume that the purchasing power parity must be performed at least in the long term for traded goods. But a considerable number of empirical studies tell about the controversial solution to the problem. On the one hand, a number of studies really confirm a close relationship of PPP and long-term changes in foreign exchange rates. The article (Hakkio, 1992) based on data for the period from 1900 identified a tendency for the return of the nominal exchange rate to its long-term values calculated by PPP in the long term of 3–12 years.

On the other hand, studies (Goodwin, Grennes, Wohlgenant, 1990) and (Frenkel, 1978) confirmed that the PPP-rate and the Law of One Price are very ill. Other studies, particularly comparison of developing and industrialized countries and in the short and in the long term, showed significant deviations of nominal exchange rates from the PPP. The results strongly depend on the calculation method of the real exchange rate — based on CPI or the GDP deflator.

Studying the ability of the PPP approach to predict future changes of the nominal exchange rate, the IMF experts (Cheung, Chinn, Pascual, 2004), based on data 1981–2002 from a number of developed countries (including the G-7) and developing countries, have come to a negative conclusion.

Model (Berka, Devereux, Engel, 2012) presents that nominal exchange rate movements give rise to persistent deviations from the Law of One Price even in traded goods.

According to the Russian statistics PPP-rate of ruble to its market rate at the end of the year varied considerably and amounted, respectively, to: in 1993–0,25, in 1997–0,7, in 1999–0,22, in 2006–0,48, in 2012–0,61 (author's calculations based on the data from Federal State Statistics Service of Russia, Central Bank of Russia and OECD).

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