UDC 336.276

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THE ANALYSIS OF MODELING OF INTEREST RATES FOR PUBLIC DEBT MANAGEMENT

АНАЛІЗ МОДЕЛЮВАННЯ ПРОЦЕНТНИХ СТАВОК ЩОДО УПРАВЛІННЯ ДЕРЖАВНИМ БОРГОМ

ANNOTATION

The components of effective debt management should be clearly interact among themselves. Interest rates directly affect the public debt, and therefore understanding how the change a particular component will affect the change of government debt in the future is extremely important. The research selected models concerning analyze changes in interest rates by the action of one or more factors, makes it possible to predict the actual change in the amount of public debt and to point out the factors that most influenced this way. CIR (Cox-Ingersoll-Ross) model and the Nelson-Siegel model played quite a significant role in the research of this issue. Their practical application can reduce the errors in forecasting, by building forecasts not by means of linear methods, but using the basic components of changes in interest rates in the face of uncertainty.

Keywords: CIR (Cox-Ingersoll-Ross) model, Nelson-Siegel model, public debt management, modeling of interest rates, change of Gross domestic product (GDP).

АНОТАЦІЯ

Складові ефективного управління державним боргом повинні чітко взаємодіяти між собою. Відсоткові ставки прямо впливають на розмір державного боргу, а отже розуміння того, як зміна того чи іншого компоненту вплине на зміну державного боргу в майбутньому є вкрай важливим. Дослідження обраних моделей щодо аналізу зміни відсоткових ставок при дії одного або більше чинників, дає можливість спрогнозувати реальні зміни в розмірі державного боргу та вказати на фактори, що найбільшим чином на це впливатимуть. Модель CIR (Cox-Ingersoll-Ross) та модель the Nelson-Siegel відіграють достатньо вагому роль у дослідженні даного питання. Їх практичне використання дозволяє зменшити похибку у прогнозуванні, за рахунок побудови прогнозів, не за допомогою лінійних методів, а використовуючи основні компоненти моделей зміни відсоткових ставок в умовах невизначеності.

Ключові слова: модель CIR (Cox-Ingersoll-Ross), модель the Nelson-Siegel, управління державним боргом, моделювання відсоткових ставок, зміна валового внутрішнього продукту (ВВП).

АННОТАЦИЯ

Составляющие эффективного управления государственным долгом должны четко взаимодействовать между собой. Процентные ставки напрямую влияют на размер государственного долга, а, следовательно, понимание того, как изменение того или иного компонента повлияет на изменение государственного долга в будущем является крайне важным. Исследование избранных моделей к анализу изменения процентных ставок при действии одного или более факторов, дает возможность спрогнозировать реальные изменения в размере государственного долга и указать на те факторы, что в наибольшей степени на это влияют. Модель CIR (Cox-Ingersoll-Ross) и модель the Nelson-Siegel играют достаточно важную роль в исследовании данного вопроса. Их практическое использование позволяет уменьшить погрешность в прогнозировании, за счет построения прогнозов, не с помощью линейных методов, а используя основные компоненты моделей изменения процентных ставок в условиях неопределенности.

Ключевые слова: модель CIR (Cox-Ingersoll-Ross), модель the Nelson-Siegel, управление государственным долгом, моделирование процентных ставок, изменение валового внутреннего продукта (ВВП).

Formulation of the problem. Public debt is not a matter of concern as long as it is manageable and sustainable. The debt management is the process by which the government acquires and uses the debt effectively and efficiently. Debt is manageable as long as the cost of acquiring debt is reasonably low and debt obtained is used efficiently in such a way that it helps growth and efficient allocation of resources in the long run. The debt is used efficiently if the ratios of debt service to total revenue and external debt service to exports fall or remain constant.

Public debt strategy is defined as the manner in which a government finances an excess of government expenditures over revenues and any maturing debt issued in previous periods. With this purpose, being developed many models of management of public debt liabilities, which include a set of components, to help anticipate further changes in the volume of debt and make some adjustments in management.

Analysis of recent of research and publications. The problem of modeling interest rates for public debt management is quite explored in Western literature. Considerable attention to research of management of public debt paid: R. Barro, A. Velandia, J. Annaert J. Buchanan, R. Musgrave, John. M. Keynes, Anouk G.P. Claes, M. Ishfaq, A. Uboldi etc. This issue is of particular relevance among local researchers, namely: S. Londar V. Basko, V. Fedosov, O. Vasylyk, T. Vakhnenko, V. Heytsya., V. Kozyuka, A. Kucher, V Lisovenko, A. Plotnikov and others. The study features the transformation of the macroeconomic environment in which growing national debt and the issue of public debt in transition T. Vakhnenko paid attention, Y. Gaidar, E. Zaruba, Z. Lutsyshyn, B. Lissitzky. The problem of public debt management considered A. Vavilov, G. Trofimov, T. Bondaruk. Analysis of public debt in the context of national security contained in the writings of A. Baranovsky.

ГРОШІ, ФІНАНСИ І КРЕДИТ

Setting objective of the article. The analysis of parts of CIR (Cox-Ingersoll-Ross) model and the Nelson-Siegel model for public debt management.

The main material of research. In general terms, the concept of sustainability of public finances concerns the ability of a government to service the costs of all its debt – internal and external alike, contracted by both public and private subjects – without endangering its perspectives for future economic growth and development.

In the countries with high levels of indebtedness, in which the interest payments absorb a significant percentage of the state budget, reducing the interest-related costs is crucial. In addition, these countries must reduce the risk that unfavorable shocks on the real performance or production growth might lead to an unsustainable indebtedness level.

As for the public debt management, the problems often start from the decision factors lack of attention to the benefits of a prudential strategy of debt management, to the costs of a poor macroeconomic management and to the excessive levels of public indebtedness. As a result, the public authorities should be more careful with the advantages deriving from a reasonable public debt management and from debt policies coordinated within a complete macroeconomic framework.

Good public debt management can help reduce borrowing cost in many ways. A well-designed and implemented borrowing program can give confidence to investors and thus reduce the lending spread. A carefully balanced composition of securities can contain risk – which are harder to manage in countries having few alternative sources of finance [3].

High debt leads generally to high debt service liability. However, the severity of the debt service liability of a country depends on the relationship of its debt to its GDP and on the level of debt in relation to its debt service obligations. As such, the absolute volume of debt of a country is not perhaps as much a matter of concern as the extent of debt service liability.

The level of debt service liability of a country may be high or low depending on its level of economic development. The incidence of debt service liability of a borrowing country is generally reflected from debt indicators expressed as ratios of debt to GNP (Debt-GNP), debt to debt-service liability (Debt-Service), debt-service to foreign exchange earnings (Debt-FEE), etc. The debt service payment may be large or small depending on the values of such debt indicators and the conditions under which loans are sought and received. As such, the values of these ratios and thereby the severity of debt burden keep changing in response to changes in the terms of borrowing and overall economic conditions of a country [2].

The Growth and Stability Pact (GSP), subscribed by the countries of the European Union (EU) in Maastricht, defines ”sound and disciplined public finances” as an essential condition for strong and sustainable growth with improved employment creation. Since in Italy the expenses for interest payments on Public Debt is about 13% of the Budget Deficit (that is the difference between revenues and expenditures) the Public Debt Management Division of the Italian Ministry of Economy and Finance is deeply interested in studying which securities to issue, in order to achieve an optimal debt composition.

The CIR (Cox-Ingersoll-Ross) indicates the level of interest rate that makes the growth rate of public debt equal to the growth rate of GDP. In addition, the maximum interest rate can be paid on loans while maintaining at the same time a desirable debt-GDP ratio. In principle, if the average interest rate on loans exceeds the CIR, debt will increase faster than GDP leading thereby to an ever-increasing debt burden [2].

Algebraically, the CIR is calculated as:

$$CIR = \frac{s_1 - s_o}{kg - s_o},$$

where g is growth rate of GDP, s_1 – marginal saving rate, s_0 – average saving rate at the beginning of the period, and k is incremental capital-output ratio. For the purpose of calculation, the values of CIR, g and k can be calculated for different time to know how the debt-servicing capacity of a country may have changed.

The optimal borrowing capacity can also be found conceptually by using a simpler model. Technically, optimal external borrowing is a function of its costs and benefits. The terms at which public debt can be obtained are crucial in determining the cost-benefit ratios. The objective is to obtain loans at such an interest rate as renders debt/GDP ratio stable over time. A stable debt/GDP ratio may depend on a particular relationship among relevant variables. The equation mentioned below connects the required variables in a relationship, which determines the convergence of external debt to a stable ratio in terms of GDP.

$$\frac{D}{Y} = \frac{(kg - s)}{(g - i)},$$

where D, Y, k, g, s and i denote public debt, Gross Domestic Product (GDP), incremental capital output ratio, growth rate of GDP, marginal saving rate and interest rate on public debt. The equation clearly shows that debt – GDP ratio is an increasing function of the interest rate on public debt. To determine the effect of a change in GDP growth rate on the debt – GDP ratio, consider the following derivative:

$$\frac{\partial(^D/_y)}{\partial g} = \frac{(g - i)k - (kg - s)}{(g - i)^2} = \frac{s - ik}{(g - i)^2},$$

$$\frac{(s - ik)}{(g - i)^2} > 0, if\ i < \frac{s}{k}\ and\ \frac{(s - ik)}{(g - i)^2} < 0, if\ i > \frac{s}{k}.$$

It follows that debt-GDP ratio will increase or decrease with the growth rate of GDP depending on whether the interest rate on public debt is less than or greater than the ratio of saving rate to incremental capital output ratio. The values of different debt indicators and CIR basically provide a future guideline for negotiations of debt restructuring or future loan negotiations. Inept management of debt and regularly rising debt to GDP are likely to induce changes in the main macroeconomic indicators like crowding out of investment, fiscal instability, inflationary pressures and exchange rate fluctuations etc. Further, rising debt burden has also many undesirable implications for the country. There is, therefore, a need to make serious attempts at finding a sustainable indigenous solution of the debt. Since debt becomes a concern when it crosses manageable and sustainable limits, policy makers are suggested to formulate a process by which government is forced to use loans effectively. Debt is used efficiently as long as the level of external debt-service and the ratio of debt service to total revenue are either falling or at least remaining constant. Public debt can be sustainable as long the projects financed with borrowed money generate sufficient output and export earnings for debt repayment.

Further, it is required to maintain capital output ratio and higher marginal saving rate to avoid unsustainable rate of interest on borrowed money [2].

National income identity shows that at any point of time, the total amount of resources available to a country that it can consume and set aside for (gross) investment or use for exports is equal to the country's gross national product plus its imports. It follows from national income identity that at any time the difference between a country's gross investment and gross domestic savings is necessarily equal to the difference between its imports and exports. Therefore, a country can invest more than it can save, and thus achieve a growth rate higher than that determined by its domestic savings rate, if it can import more than its exports by the same amount. This will naturally depend upon how it finances the import surplus. Whether the country relies on private net capital inflow or borrows publicly, a net borrowing remains the only offsetting item in the balance of payments to finance the deficits. Thus, the role of public debt in a growing economy is quite obvious. A given amount of public debt can finance an equal amount of import-surplus of the capital receiving country and also allow its investment to exceed its domestic saving by the same amount, that is:

$$I_t - S_t = M_t - X_t = F_t,$$

where I_t ,S_t ,M_t, X_t and Ft denote gross investment, gross domestic savings, imports, exports and net funding (borrowing), respectively. If gross incremental capital-output ratio is denoted by k, and growth rate of GDP by g, then:

$$I_t = kgY_t ,$$

where Y_t is GNP at time t. The rate of savings is expected to rise over time. Let s_o be the average rate of savings at the initial period, that is period zero, and s_m the incremental savings rate between period zero and t. We assume that the saving function is of the following form.

$$S_t = s_o Y_o + s_m(Y_t - Y_o) = (s_o - s_m)Y_o + s_m Y_t,$$

Substituting the previous formulas get the following:

$$kgY_t - [(s_o - s_o)Y_o + s_m Y_t] = F_t,$$

$$g = {}^1/_k \left[(s_o - s_{m)} \frac{Y_o}{Y_t} + s_m + \frac{F_t}{Y_t}\right].$$

The last equation gives a unique relationship between the growth rate of GDP, g, and the net borrowing as a proportion to GDP i.e.: F_t/Y_t.

Given the incremental capital-output ratio, marginal rate of savings, average savings rate at the initial period and the initial and the current level of GDP; we can obtain either the net borrowing required by a target rate of growth, or the rate of growth that can be achieved with a given amount of borrowing. Since ∂, g/∂, $F >0$, a large borrowing can achieve a higher rate of GDP growth, keeping all other factors constant [2].

The above formulation can also be used to measure the capacity of the country to absorb borrowed funds. The proposition on which the above argument i.e. the rate of growth can be raised by increasing the rate of investment financed by borrowing is based, implicitly assumes that capital, not labor, is the main bottleneck for raising the rate of growth. This way of looking at the relationship between borrowed money and the rate of growth of GDP implies that every year the import – surplus somehow gets adjusted to the net inflow of public debt. Total imports adjust automatically to the two exogenous variables i.e.: X_t, F_t and the growth rate entirely depends on how far F_t can eliminate the bottleneck of the low rate of domestic savings. However, imports may not be so freely adjustable in an underdeveloped country and thus a more comprehensive model will inevitably contain additional constraints. For that purpose, we assume that there is a rigid relationship between the level of imports required and the level of GDP. The assumption that there is a minimum import requirement corresponding to a level of GDP can be interpreted in two ways [2].

First, the import requirement is in fixed proportions to consumption, gross investment and exports, which, as a first approximation may be regarded as the same. Such an assumption may be questionable for an underdeveloped economy at an early stage of development where imports to consumption ratio may be much higher due to the imports of some basic necessities for supporting its subsistence level of consumption. The case may be similar with exports if they are not completely given exogenously. But even if there exist consumption and export basket with negligible minimum import requirements, it is quite possible that gross investment required for maintaining that level of consumption and exports over time may need some minimum level of imports. The minimum level of imports is required simply because certain right types of equipment, machinery, etc. are not domestically produced.

In the case where only a given amount of loan is available to finance the gap between savings and investment, the funding may not achieve the target of growth rate of GDP as determined by the capital output ratio. This is because imports may increase due to increase in income and this increase in imports may exceed the exports by more than the given amount of borrowed funds [2].

In either case, the condition for a given amount of debt to achieve a rate of GDP growth determined by the amount of savings – investments gap it can finance, is that $M \leq X+F$, with M accounting for the minimum level of imports. If this condition is not fulfilled, there will be two operative constraints on the growth level of GDP, namely the resource constraint $I\text{-}S \leq F$ and the balance of payment constraint $M\text{-}X \leq F$. The solution of the system will depend upon which of the two constraints is more restrictive, i.e. whichever gives the lower solution.

It is also adopted that this upper bound on GDP growth rate, determined by the import constraint becomes less and less restrictive with time as rising GDP is likely to be accompanied by increasing availability of domestically produced capital goods. Thus, in the long run, the saving-investment gap that will determine the effect of borrowing capital on the growth rate of GDP, although in the early phase of development the import constraint may be more important [2].

The following analysis is mainly focused on the debt inflows filling the saving-investment gap. Although, this renders the analysis partial in nature, but it may be still worthwhile mainly for two reasons:

1) even if there were no import constraints, the effect of public debt on growth rate will depend on how far it overcomes the savings constraint;

2) it may be maintained that in the long run it is the saving constraint that is more restrictive than the imports constraints.

The other models that is used for calculating interest rates for public debt management are **the Nelson-Siegel model and Svensson model**.

The original motivation for this modelling method was a desire to create a parsimonious model of the forward interest rate curve that could capture the range of shapes generally seen in yield curves: a monotonic form, humps at various areas of the curve, and s-shapes. This is one possibility among numerous potential functional forms that could be used to fit a term structure. The Svensson model is a good choice, given its ability to capture the stylized facts describing the behavior of the forward curve [5].

These models have six parameters that must be estimated, β_0, β_1, β_2, β_3, τ_1, and τ_2. These parameters identify four different curves, an asymptotic value, the general shape of the curve, and two humps or U-shapes, which are combined to produce the Svensson instantaneous forward curve for a given date. The impact of these parameters on the shape of the forward curve can be described as follows (Figure 1):

– β_0 – this parameter, which must be positive, is the asymptotic value of $(TTM)t$. The curve will tend towards the asymptote as the (term to maturity) TTM approaches infinity;

– β_1 – this parameter determines the starting (or short-term) value of the curve in terms of deviation from the asymptote. It also defines the basic speed with which the curve tends towards its long-term trend. The curve will have a neg-

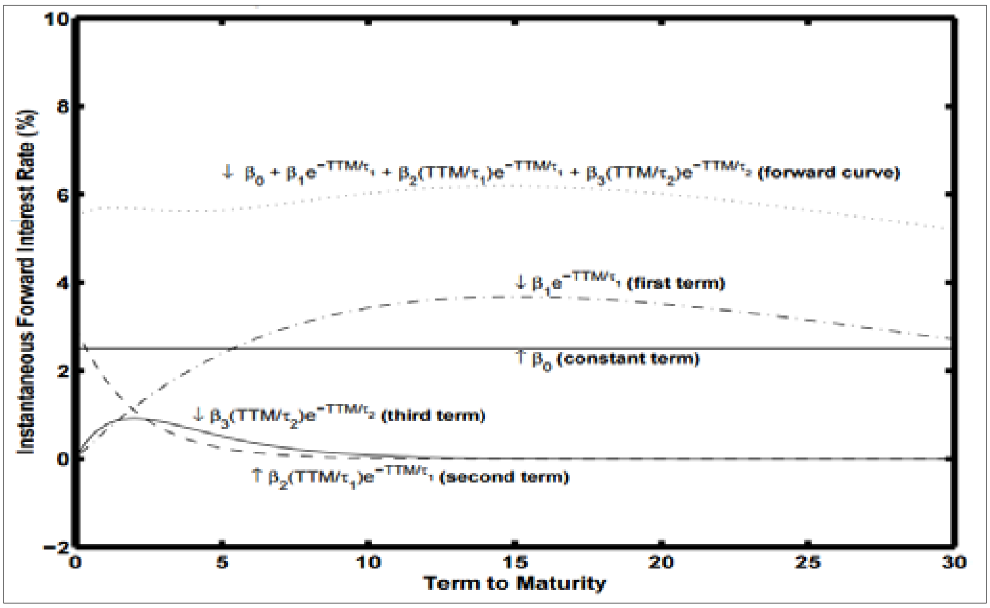

Fig. 1. A decomposition of the forward term structure functional form

Source: Technical Report # 84 of the Bank of Canada [5] ative slope if this parameter is positive and vice versa. Note that the sum of β_0 and β_1 is the vertical intercept;

– τ_1 – this parameter, which must also be positive, specifies the position of the first hump or U-shape on the curve;

– β_2 – this parameter determines the magnitude and direction of the hump. If β_2 is positive, a hump will occur at τ_1 whereas, if β_2 is negative, a U-shaped value will occur at τ_1;

– τ_2 – this parameter, which must also be positive, specifies the position of the second hump or U-shape on the curve;

– β_3 – this parameter, in a manner analogous to β_2, determines the magnitude and direction of the second hump.

Having specified a functional form for the instantaneous forward rate, a zero-coupon interest rate function is derived. This is accomplished by integrating the forward function. This is possible, given that the instantaneous forward rate (which is simply the marginal cost of borrowing) is the first derivative of the zero-coupon rate (which is similarly the average cost of borrowing over some interval).

Once the functional form is specified for the forward rate, it permits the determination of the zero-coupon function and finally provides a discount function. The discount function permits the discounting of any cash flow occurring throughout the term-to-maturity spectrum [1].

The NS model is an example of a so-called parsimonious model. The main idea behind these models is to postulate a unique functional form for the whole range of maturities for the discount function or, it is analogous, for particular rates as the forward or the spot rates. The NS model tries to capture some properties of the term structure thanks to the functional form imposed on the forward interest rates [4].

The idea of Nelson and Siegel is trivial but ingenious: the discount function is the derivative of the price and the forward rate is linked to the derivative of the discount function, hence the forward rate will be linked to the second derivative of the price.

Therefore, it is reasonable to think that the form of the forward rate will be similar to the solution of a second order differential equation:

$$f(t) = \beta_0 + \beta_1 e^{-\frac{1}{\tau}} + \beta_2 \frac{t}{\tau} e^{-\frac{t}{\tau}}.$$

The parameters of this model have a clear financial meaning, as can be seen here:

$$\lim_{t\to\infty} f(t) = \beta_0$$

$$\lim_{t\to 0} f(t) = \beta_0 + \beta_1$$

$$\lim_{t\to\tau} f(t) = \beta_0 + \frac{\beta_1+\beta_2}{e}.$$

Clearly, β_0 is the long-term forward rate; the short-term forward rate is modulated by β_1 and the medium-term forward rate is modulated by β_2. In addition, the parameter τ has an interesting rule: the amount of time τ separates the short from the medium-long term. For instance, in a working paper on the Italian secondary bond market, has been shown that τ is generally included between 12 months and 18 months, and this result agrees with the practitioner's thought [4].

There are different reasons to use the Nelson-Siegel model:

1. The NS model is very easy to implement and, as we have seen, this property is very important for financial institutions.

2. The parameters of the model have a clear financial meaning and this is very useful for a practitioner.

3. The NS model determines a very stable term structure. It is possible to understand the sense of this sentence with an example: if there were not a shock between today and tomorrow the bond prices would change, but it is reasonable to believe that the term structure of tomorrow will be very similar to the term structure of today. In other words, until it occurs a shock, the term structure will remain roughly constant. Hence, if a model is too sensitive to bond prices, i.e.: if it generates completely different term structures one day after another even when there is not any shock, that model is not a good model for our purposes. The NS model generates stable term structure and so from a practical point of view it is a good model.

4. The yield curve generated by NS model does not explode in the long term. Many institutions generate the term structure with regression techniques like, for example, splines and bi-splines. The NS model does not share this problem, because the forward rate, and as consequence the discount function d(t), tends to an asymptotic constant, as can be seen in the following formula:

$$\lim_{t\to\infty} d(t) = \lim_{t\to\infty} e^{-t\left[\beta_0+(\beta_1+\beta_2)\frac{\tau}{t}\left(1-e^{-\frac{1}{\tau}}\right)-\beta_2 e^{-\frac{1}{\tau}}\right]} = c^{-(\beta_1+\beta_2)\tau}.$$

5. For the Italian secondary bond market, has been shown that the characteristic times of the three parameters β_i, (i=0, 1, 2) are completely diffrent from each other. In particular, the characteristic time of β_0 is greater than 1 year, the characteristic time of β_1 is about 2 days and the characteristic time of β_2 is about 6 months. Hence, diffrent maturities of the NS term structure can have movements with diffrent intensities and diffrent directions.

Consequently, Nelson and Siegel propose that with appropriate choices of weights for these three components, it is possible to generate a variety of yield curves based on forward rate curves with monotonic and humped shapes.

Svensson model (1994) extended Nelson-Siegel model by introducing additional parameters that allow yield curve to have an additional hump. Thus, this model is considered to be computably more demanding. Svensson suggested forward curve to be estimated as [6]:

$$f(TTM)_t = \beta_0 + \beta_1 e^{-\frac{TTM-1}{\tau_1}} + \beta_2 \frac{TTM-1}{\tau_1} e^{-\frac{TTM-1}{\tau}} + \beta_3 \frac{TTM-1}{\tau_2}.$$

From this the relation it can be noticed that the β_2 is identical to the β_2 term with τ_1 replaced by τ_2. The two additional parameters β_3 and τ_2 explain the extended flexibility of the Svensson approach. The linear parameter β_3 defines the form (convex or concave) of the second hump of the spot interest rate curve, and the non-linear parameter τ_2, like τ_1 in the Nelson-Siegel model, defines it position.

In the practice Nelson-Siegel model is preferred for the use especially where there are few input data. Nelson and Siegel (1987) demonstrated that their proposed model is capable of capturing many of the typically observed shapes that the spot rate curve assumes over time. A significant weakness of the Nelson-Siegel model, resulting from its low elasticity, is goodness of fit that is lower than in the case of polynomial models. When the curve is fitted to an irregular set of data points this can result in relatively large deviations of model values from actually observed rates. The extended Nelson-Siegel model by Svensson offers a satisfactory precision of fit and a smooth shape of implied forward curve. Svensson model has a number of weaknesses, e.g. a limited ability to fit irregular yield curve shapes, a tendency to take extreme values at the short end, and a relatively strong co-dependence of estimates in different – even non-neighboring – segments of the yield curve. Thus, sometimes calculations using Nelson-Siegel model can be more correct [6].

Therefore, the return of the activity on a lethargic secondary market of public debt is most definitely of great interest for the issuer, i.e. government, and after all the development and improvement of the domestic securities is defined as one of the Government goals in February 2011. In the year 2012, the liquidity increases which increases optimism and gives hope for the future developments.

Conclusion. Hence, were described the CIR model and the NS model and was also compared with each other. From the analysis, we can conclude with some suggestions:

1. The lack of information on the short term can be extremely dangerous, especially for regression models like the NS model;

2. For the medium and long-term maturities of the term structure, both the NS model and the CIR model are good choices. On the other hand, approaches that use spline and bi-spline, like McCulloch in, lead to an explosion of the curve;

3. For the short-term maturities of the term structure, the CIR model is better than the NS model, because it is less sensitive to the lack of information in the first part of the data set;

4. Both models can describe the trends of the returns on the different maturities of the term structure;

5. It seems reasonable to implement fundamentalist strategies based on the mean spread between the market price and the theoretical CIR price of a bond.

This analysis makes it possible to assert the fundamental importance of proper use of interest rates. Interest rates directly affect to extent of debt load, which allows the simulation indicate the need for interest rates in the general model of debt management.

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