BEST FIT MODEL FOR YIELD CURVE ESTIMATION

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Abstract

Yield curve represents a relationship between the rate of return and maturity of certain securities. A range of activities on the market is determined by the abovementioned relationship; therefore its significance is unquestionable. Besides that, its shape reflects the shape of the economy, i.e. it can predict recession. These are the reasons why it is very important to properly and accurately estimate the yield curve. There are various models evolved for its estimation; however the most used are parametric models: Nelson-Siegel model and Svensson model.

In this paper the yield curves are estimated on Croatian financial market, based on weekly data in years 2011 and 2012 both with Nelson-Siegel and Svensson model, and the obtained results are compared.

Key words: *yield curve, Nelson-Siegel model, Svensson model, Croatian financial market*

1. INTRODUCTION

The yield curve, as a picture of relationships between the yields on bonds of different maturities, provides a way of understanding the common markets' evaluation in the future, and whether the economy will be strong or weak (Cano, Correa and Ruiz, 2010).

Interest rates movements depend on the maturity period and the form of the yield curve has a great effect on the financial markets and the behaviour of financial intermediaries. Intermediaries will, to maximize their own profits, take into account the difference between short-term and long-term interest rates. A full range of activities in the financial markets is actually determined by the relationship between the interest rate and maturity. Yield curve can be observed from micro and macro aspects. From micro aspect yield curve helps investors alerting them on the possible recession or the upturn of the economy. The yield curve can be used as a benchmark for pricing other securities with fixed interest rates. By predicting movements in the yield curve, managers of fixed interest rates may attempt to earn above-average returns on their portfolios of bonds. Several strategies are developed to get the above-average returns in different interest rate environments. Macro aspect of yield curve highlights the importance of the term structure of interest rates for macroeconomic analysis because of its effects on the consumer decisions and investment decisions of economic agents and thus aggregate demand, which is one of the determinants of inflation in the economy. From a financial standpoint, the existence of the yield curve favours the development of domestic capital markets, primary and secondary, allowing the recovery of financial instruments (debt and derivatives) (Pereda, 2009).

Table 1: Central banks and yield curve models

CENTRAL BANK	***MODEL***
Belgium	Nelson-Siegel, Svensson
Canada	Svensson
USA	Fisher-Nychka-Zervos (Spline)
Finland	Nelson-Siegel
France	Nelson-Siegel, Svensson
Germany	Svensson
Italy	Nelson-Siegel
Japan	Fisher-Nychka-Zervos (Spline)
Norway	Svensson
Spain	Svensson
UK	Anderson and Sleath (Spline) (until 2001 Svensson)
Sweden	Fisher-Nychka-Zervos (Spline), before Svensson
Switzerland	Svensson
EU	Svensson

Source: Pereda, J. (2009) , “Estimación de la Curva de Rendimiento Cupón Cero para el Perú”, Banco Central de reserva del Perú, Revista Estudios Económicos N° 17

To estimate the yield curve central banks use different models. The table 1 provides a review of the use of certain types of models in some countries

It can be seen that in the most foreign countries dominate Svensson and Nelson-Siegel models. Both models have their advantages and disadvantages. Nelson Siegel model is extremely popular in the practice; both individual investors and the central banks use this model. This model is simple and stable for the evaluation, it is quite flexible and very well suited for assessing yields for more bonds or one bond and for the time series of returns, for a large number of countries and time periods and for different classes of bonds. It also has good prediction ability (Marciniak, 2006). Second quite used model is Svensson model. Svensson model is an extension of the Nelson-Siegel model, which provides sufficient precision adjustment and smooth curve shape of periodic rents. It has become very popular in the mid 90's. Since then, it has been used by the substantial number of central banks worldwide to assess the bond structure with a single coupon and future interest rates (forward rates). However, the model has a number of weaknesses, such as limited ability to adapt irregular shapes of the yield curve, the tendency of taking extreme values at the bottom of the curve and a relatively strong dependence on the estimations in different or even nonadjacent segments of the yield curve (Marciniak, 2006).

In this paper yield curves on Croatian financial market are calculated on weekly basis from 7^{th} October 2011 to 24^{th} August 2012 using both Nelson-Siegel and Svensson model. The results are compared in order to find out the best fitting model on Croatian financial market for the yield curve evaluation.
In the first part of the paper theoretical overview of the yield curve is provided, followed by the explanation of the two most commonly used models for yield curve evaluation. In the third part of the paper current situation on the Croatian financial market is explained. Finally, yield curves are calculated and empirically tested using both models on Croatian financial market.

2. NELSON-SIEGEL MODEL

Often used model for developing yield curve in the practice is the Nelson-Siegel model (Nelson and Siegel, 1987). Nelson and Siegel introduced a simple, parsimonious model, which can adapt to the range of shapes of yield curves: monotonic, humped and S shape.

A class of functions that readily generates the typical yield curve shapes is that associated with solutions to differential or difference equations (Aljinović, Marasović and Škrabić, 2009). If the instantaneous forward rate at maturity T, $f(t,T)$, is given by the solution to a second-order differential equation with real and unequal roots, it is of the form:

$$f\left(t,T\right)=\beta_0+\beta_1 e^{-\frac{T-t}{\tau_1}}+\beta_2 e^{-\frac{T-t}{\tau_2}} \tag{1}$$

where τ_1 and τ_2 are time constants associated with the equation, and β_0, β_1 and β_2 are determined by initial conditions.

Now, zero-coupon rates $R\left(t\right)$ can be calculated by averaging the corresponding instantaneous forward rates:

$$R\left(t,T\right)=\frac{1}{T-t}\int_t^T f\left(x,T\right)dx \tag{2}$$

A more parsimonious model that can generate the same range of shapes is given by the equation solution for the case of equal roots:

$$f\left(t,T\right)=\beta_0+\beta_1 e^{-\frac{T-t}{\tau}}+\beta_2\frac{T-t}{\tau}e^{-\frac{T-t}{\tau}} \tag{3}$$

By substituting (3) into (2) and integrating, it is obtained:

$$\begin{aligned}R\left(t,T\right)&=\frac{1}{T-t}\int_t^T f\left(x,T\right)dx=\frac{1}{T-t}\int_t^T\left(\beta_0+\beta_1 e^{-\frac{T-t}{\tau}}+\beta_2\frac{T-t}{\tau}e^{-\frac{T-t}{\tau}}\right)dx=\\&=\frac{1}{T-t}\left(\beta_0\left(T-t\right)-\beta_1\tau e^{-\frac{T-t}{\tau}}+\beta_1\tau+\beta_2\tau\left(-\frac{T-t}{\tau}e^{-\frac{T-t}{\tau}}-e^{-\frac{T-t}{\tau}}+1\right)\right)\end{aligned} \tag{4}$$

After a simple rearrangement of this expression, the yield to maturity is given by:

$$R\left(t,T\right)=\beta_0+\left(\beta_1+\beta_2\right)\frac{1-e^{-\frac{T-t}{\tau}}}{\frac{T-t}{\tau}}-\beta_2 e^{-\frac{T-t}{\tau}} \tag{5}$$

So, the forward and zero-coupon yield curves are functions of four parameters: β_0, β_1, β_2 and τ.
It can be seen that

$$\lim_{T\to\infty}R\left(t,T\right)=\beta_0 \tag{6}$$

and β_0 corresponds to zero-coupon rates for very long maturities.

At the short end of the curve it is:

$$\lim_{T\to t}R\left(t,T\right)=\beta_0+\beta_1 \tag{7}$$

which implies that the sum of parameter values β_0 and β_1 should be equal to the level of the shortest interest rates.

It can be seen that if β_1 is negative, the forward curve will have a positive slope and other way round. The parameter β_2, indicates the magnitude and the direction of the hump and if it is positive, a hump will occur at τ whereas,. In case it is negative, a U-shaped value will occur at τ. So it can be concluded that parameter τ which is positive, specifies the position of the hump or U-shape on the entire curve. 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 (Aljinović, Marasović and Škrabić, 2009).

3. SVENSSON MODEL

Svensson (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 (Andraž, 2006):

$$f\left(t,T\right)=\beta_0+\beta_1 e^{-\frac{T-t}{\tau_1}}+\beta_2\frac{T-t}{\tau_1}e^{-\frac{T-t}{\tau_1}}+\beta_3\frac{T-t}{\tau_2}e^{-\frac{T-t}{\tau_2}} \tag{8}$$

The corresponding yield to maturity is of the form:

$$R\left(T,t\right)=\beta_0+\beta_1\frac{1-e^{-\frac{T-t}{\tau_1}}}{\frac{T-t}{\tau_1}}+\beta_2\left(\frac{1-e^{-\frac{T-t}{\tau_1}}}{\frac{T-t}{\tau_1}}-e^{-\frac{T-t}{\tau_1}}\right)+\beta_3\left(\frac{1-e^{-\frac{T-t}{\tau_2}}}{\frac{T-t}{\tau_2}}-e^{-\frac{T-t}{\tau_2}}\right) \tag{9}$$

From the relation (8) 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 (Ganchev, 2008).

4. MAIN CONCLUSIONS OF PREVIOUS RESEARCHES ON NELSON-SIEGEL AND SVENSSON MODELS

The Nelson-Siegel model, which has only four parameters, enables us to estimate the yield curve, without being over-parameterized, when the number of observed bond prices is limited (Kladivko, 2010). In the practice Nelson-Siegel model is preferred for the use especially where there are few input data (Rohde, 2007). 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 (Berec, 2010). 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 (Marciniak, 2006).

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-neighbouring – segments of the yield curve (Marciniak, 2006). Thus sometimes calculations using Nelson-Siegel model can be more correct.

5. CROATIAN FINANCIAL MARKET SITUATION

Worldwide financial crisis had its effects on the Croatian market. Complete inactivity on the secondary market of the public debt still remains. There exists a marginal bond trade, treasury bills trade is not transparent enough, and due to its low returns, they are not in the focus neither for pension nor investment funds. Lately, there are some movements and asset growth under bond mutual funds. However, these trends are not sufficient to lead to a considerable growth in activity on secondary market. Under these conditions the primary market still functions, i.e. new issues of government bonds are, without any bigger problems, sold out. However, total illiquidity on a secondary market most certainly influences, and in future will influence even more, the price on which the government indebts. 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 (Štimac, 2012). In the year 2012 the liquidity increases which increases optimism and gives hope for the future developments (HNB, 2012).

6. YIELD CURVE ESTIMATION USING NELSON-SIEGEL AND SVENSSON MODEL ON CROATIAN FINANCIAL MARKET

In Croatia still does not exist an official yield curve due to a scarce issue of Croatian bonds denominated in Kuna and weak trade on a secondary market. In order to calculate yield curve on a Croatian financial market data from Zagreb money market, where data for treasury bills can be found, and Reuters data base, where data for government bonds can be found, is collected. Yield curves are calculated on a weekly basis from 7^{th} October 2011 to 24^{th} August 2012 using both Nelson-Siegel and

Svensson model. Even though on these dates there was pour trade on treasury bills and bonds (on observed dates the number of securities traded was mostly 10), yield curves are successfully estimated using above mentioned formulas.

Parameters β_0, β_1, β_2 and τ are estimated for Nelson-Siegel model, and β_0, β_1, β_2 and τ_1 and τ_2 for Svensson model in MS Office Excel using least square method with quasi-Newton. In the case where it was particularly difficult to estimate parameters, using Simplex method in Statistica starting points for an estimation of parameters are generated. These appropriate start values are then used in subsequent quasi-Newton iterations[1].

R^2 gives information about the goodness of fit of these models and provide an answer which model fits better to the data, i.e. which model approximates better to the real data points. It indicates the percent of total variation in interest rate which can be explained by the model.

Figure 1 displays interest rates and yield curves on Croatian financial market on 7th October 2011 (the parameters for both models and determination coefficient are presented in Table 2). Apart from the figure that shows how Svensson model clearly fits to the data better than Nelson-Siegel model, determination coefficients for Svensson model are in every case higher than for Nelson-Siegel model which leads to the conclusion that Svensson model is the best fit model for yield curve estimation. For Nelson-Siegel model parameter β_0 corresponds to zero-coupon rates for very long maturities and equals 7.29%. The sum of parameters β_0 and β_1 represents the level of the shortest interest rates and equals 1.41%. Since β_1 is negative, the curve has a positive slope. The parameter β_2, indicates the magnitude and the direction of the hump at time τ and since it is nearly equal to zero the curve has a monotonic shape. Based on R^2 92.33% of total variation in interest rates can be explained by the Nelson-Siegel model. In Svensson model the long term interest rate equals 7.16%, the short term interest rate is 0.11%, the parameter β_2 which is negative indicates that an U-shape occurs at time τ_1=0.5 and β_3 which is positive indicates the position of a hump at time τ_2=0.06. 95.78% of total variation in interest rates can be explained by the Svensson model.

[1] *Simplex* method is generally less sensitive to local minima and is usually used in combination with the *quasi-Newton* method (StatSoft)

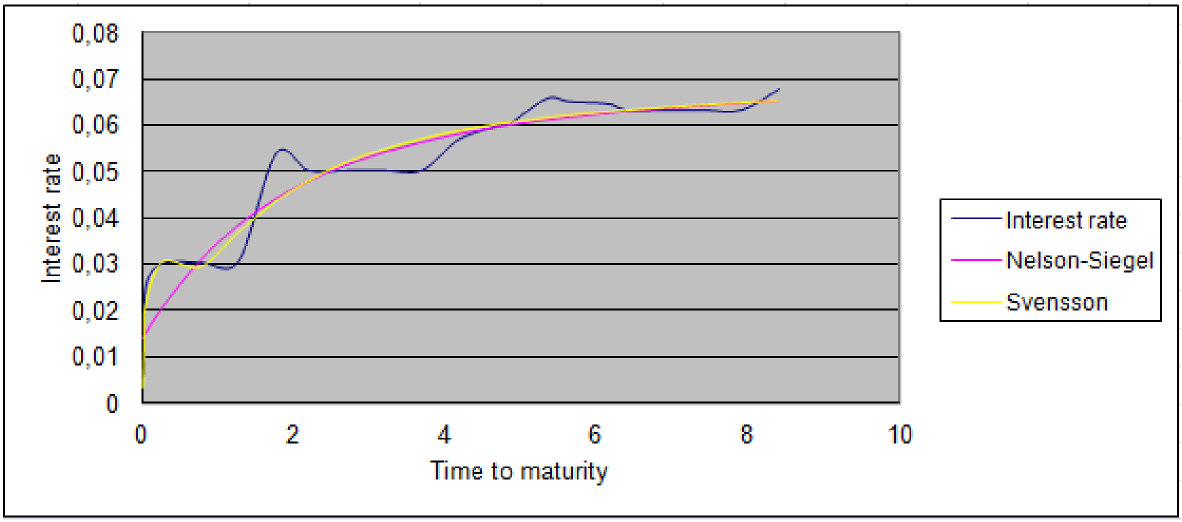

Figure :1 Interest rates and yield curves using Nelson Siegel and Svensson model on 7th October 2011

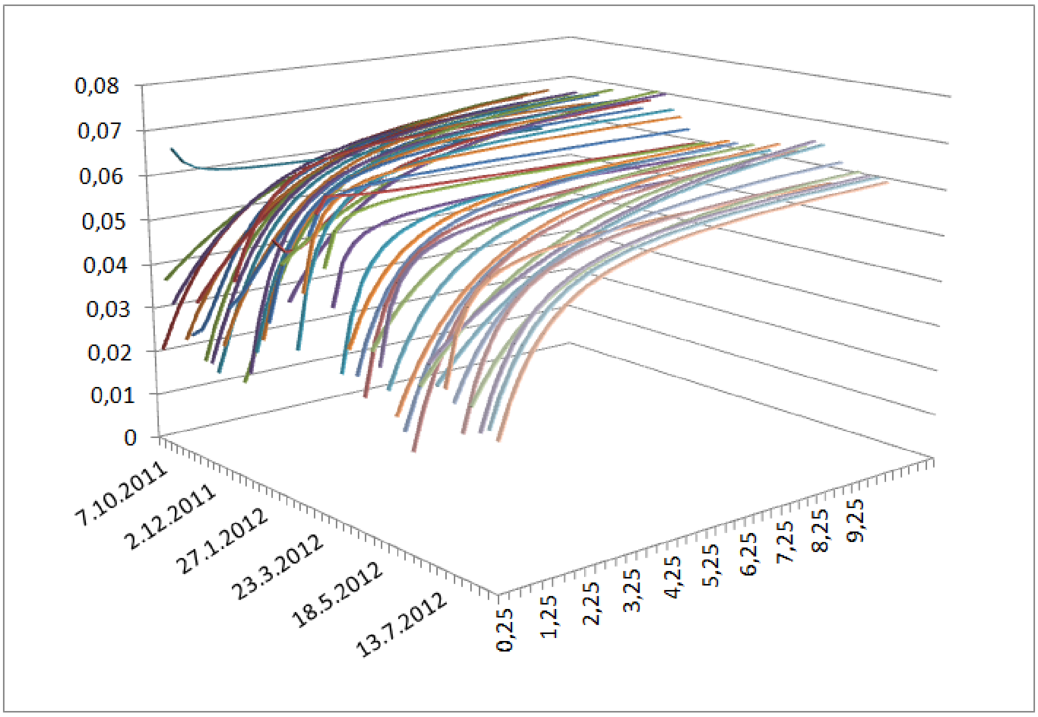

Figure 2: Yield curves on Croatian financial market using Nelson-Siegel model

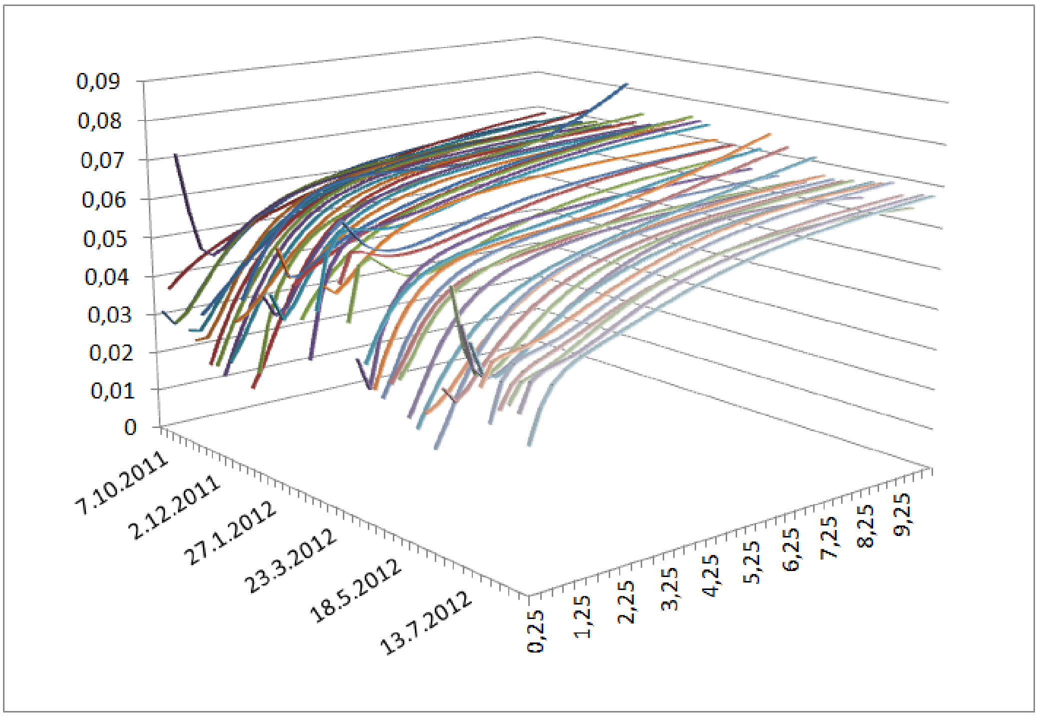

Figure :3 Yield curves on Croatian financial market using Svensson model

Figures 2 and 3 show yield curves calculated and drawn, firstly with Nelson-Siegel and secondly with Svensson model on weekly basis from 7th October 2011 to 24th August 2012 with associated interest rates and quarterly time to maturity, based on parameters estimated and presented in Table 2. Using Svensson model the yield curves show additional hump that occurs in data, as an opposite to Nelson-Siegel model where in most cases the hump is not recorded.

Table 3 shows t-statistics for the difference between two determination coefficients. With the significance of 1% it can be concluded that Svensson model fits better to the data than Nelson-Siegel model. On average 88.94% of total variation in interest rates can be explained by the Nelson-Siegel model and 93.36% of total variation in interest rates can be explained by the Svensson model.

Table 1: Nelson-Siegel and Svensson model parameters with R^2 on Croatian financial market from 7th October 2011 to 24th August 2012

Date	Nelson-Siegel model					Svensson model						
	B0	B1	T	B2	R2	B0	B1	T1	B2	B3	T2	R2
7.10.2011	0,0729	-0,0588	1,0560	0,0000	0,9233	0,0716	-0,0705	0,5069	-0,0495	0,1006	0,0663	0,9578
14.10.2011	0,0711	-0,0362	3,8677	0,0348	0,9366	0,0797	-0,0455	1,3734	-0,0771	0,0555	1,0906	0,9382
21.10.2011	0,0576	-0,0295	2,8307	0,0623	0,8986	0,0684	-0,0379	0,6085	-0,8667	0,8318	0,6252	0,9108
28.10.2011	0,0596	-0,0577	0,0562	0,0970	0,8267	0,0684	-0,0619	0,2243	-0,7168	0,8189	0,1774	0,9609
4.11.2011	0,0765	-0,0571	1,1971	0,0000	0,9227	0,0753	-0,0731	0,8897	0,0000	0,1193	0,0359	0,9640
11.11.2011	0,0728	-0,0364	0,3428	-0,0894	0,9325	0,0713	-0,0349	0,5072	0,6029	-0,6735	0,4804	0,9339
18.11.2011	0,0460	-0,0150	3,9361	0,0947	0,8304	0,0715	-0,0398	1,1833	0,1586	-0,1609	1,0552	0,8317
25.11.2011	0,0740	-0,0610	0,9600	0,0142	0,9057	0,1051	-0,0919	2,0201	0,2317	-0,2436	2,7959	0,9063
2.12.2011	0,0748	-0,0598	0,4621	-0,0355	0,9296	0,0724	-0,0575	0,9104	0,1745	-0,1625	0,8336	0,9302
9.12.2011	0,0743	-0,0600	0,4010	-0,0446	0,9458	0,0726	-0,0581	0,6313	0,8840	-0,8972	0,6173	0,9465
16.12.2011	0,0659	-0,0451	1,9964	0,0596	0,8563	0,0722	-0,0498	0,6137	-0,7824	0,7567	0,6345	0,8603
23.12.2011	0,0754	-0,0396	0,5298	-0,0468	0,5788	0,0722	-0,0362	0,7845	-0,8292	0,8047	0,8100	0,5806
30.12.2011	0,0694	-0,0356	0,8062	0,0267	0,8435	0,3556	-0,3213	3,3583	2,8900	-3,3756	3,7772	0,8534
6.1.2012	0,0774	-0,0596	0,3980	-0,0600	0,9025	0,0748	-0,0568	0,5803	-0,8325	0,8005	0,6021	0,9038
13.1.2012	0,0732	-0,0675	0,3933	0,0000	0,9464	0,0834	-0,0783	0,3573	0,0000	-0,0378	1,7753	0,9523
20.1.2012	0,0739	-0,0579	0,4987	0,0000	0,9087	0,0747	-0,0721	0,1705	-2,6973	2,7054	0,1629	0,9724
27.1.2012	0,0732	-0,0539	0,4663	0,0000	0,8930	0,0748	-0,1106	0,0085	0,2492	-0,1295	0,2509	0,9574
3.2.2012	0,0713	-0,0495	0,3544	0,0000	0,9210	0,0749	-0,0644	0,6695	0,0000	0,1538	0,0657	0,9721
10.2.2012	0,0751	-0,0123	0,4562	-0,0609	0,8388	0,0804	-0,0171	0,2623	-0,0557	-0,0384	1,2241	0,8616
17.2.2012	0,0808	-0,0337	2,3381	0,0048	0,9453	0,0819	-0,0351	1,2197	-0,0894	0,0719	1,0807	0,9463
24.2.2012	0,0783	-0,0407	1,1015	0,0000	0,8347	0,0864	-0,0496	1,6376	-0,2668	0,2691	1,5207	0,8364
2.3.2012	0,0721	-0,0642	0,2400	0,0000	0,9450	0,0816	-0,0742	0,5645	0,1691	-0,1403	0,8497	0,9580
9.3.2012	0,0700	-0,0560	0,1340	0,0000	0,8501	0,0800	-0,0658	0,6744	-0,1580	0,2190	0,4383	0,8766
16.3.2012	0,0670	-0,0531	0,0478	0,0000	0,8964	0,0734	-0,0631	0,4865	0,0000	0,1165	0,0675	0,9874
23.3.2012	0,0638	-0,0607	0,0954	0,0694	0,8933	0,0743	-0,0708	0,1409	0,1072	-0,0660	0,7727	0,9528

30.3.2012	0,0645	-0,0563	0,1056	0,0284	0,8818	0,0766	-0,0684	0,1585	0,0601	-0,0613	0,9650	0,9151
6.4.2012	0,0626	-0,0607	0,0815	0,0000	0,8300	0,0741	-0,0723	0,4285	1,3427	-1,2840	0,4673	0,8954
13.4.2012	0,0653	-0,0565	0,2321	0,0000	0,9198	0,0672	-0,8398	0,0717	-1,0260	8,6515	0,0132	0,9663
20.4.2012	0,0681	-0,0391	0,5852	0,0000	0,9461	0,0857	-0,0573	1,9378	-0,0657	0,0830	1,0218	0,9542
27.4.2012	0,0680	-0,0464	0,5217	0,0018	0,8625	0,2559	-0,2344	11,5887	-0,1351	0,0908	1,0857	0,8691
4.5.2012	0,0654	-0,0566	0,2860	0,0000	0,9690	0,0671	-0,0650	0,3918	0,0000	0,0771	0,0363	0,9875
11.5.2012	0,0699	-0,0363	1,0609	0,0000	0,9552	0,1049	-0,0693	0,3245	-0,0729	-0,1160	2,6969	0,9798
18.5.2012	0,0631	-0,0562	0,1569	0,0000	0,9443	0,0662	-0,0637	0,3717	0,0000	0,0733	0,0604	0,9835
25.5.2012	0,0690	-0,0447	0,7450	0,0000	0,9445	0,0672	-0,0409	0,3401	-0,3334	0,2925	0,3493	0,9491
1.6.2012	0,0726	-0,0524	1,0078	0,0000	0,9792	0,0992	-0,0795	2,1437	-5,0478	5,0358	2,1212	0,9807
8.6.2012	0,0702	-0,0542	0,7812	0,0000	0,9127	0,0727	-0,0710	0,8550	0,0000	0,0685	0,0994	0,9542
15.6.2012	0,0705	-0,0606	0,6330	0,0000	0,9718	0,0707	-0,0680	0,6043	-0,0001	0,0456	0,0465	0,9866
22.6.2012	0,0713	-0,0402	2,7827	0,0313	0,7882	0,0716	-0,0666	0,8059	0,0000	0,1245	0,0489	0,9787
29.6.2012	0,0792	-0,0422	2,3586	0,0000	0,6154	0,0726	-0,0584	0,4558	-0,0972	0,1797	0,1069	0,9441
6.7.2012	0,0769	-0,0444	1,7828	0,0000	0,6854	0,0088	0,0034	4,3716	0,1801	0,1404	0,0775	0,9169
13.7.2012	0,0619	-0,0490	0,1801	0,0000	0,8503	0,0736	-0,0689	0,9757	0,0000	0,1384	0,0842	0,9957
20.7.2012	0,0694	-0,0419	0,8197	0,0000	0,9258	0,0473	-0,0260	4,4552	0,1025	0,0603	0,2402	0,9981
27.7.2012	0,0659	-0,0497	0,4400	0,0000	0,9391	0,0756	-0,0633	0,6421	-0,1437	0,1585	0,4186	0,9779
3.8.2012	0,0688	-0,0394	1,0312	0,0000	0,9240	0,0718	-0,0445	0,6645	-0,1029	0,0931	0,4577	0,9424
10.8.2012	0,0667	-0,0462	0,5670	0,0000	0,9450	0,0495	-0,0324	3,0436	0,0882	0,0613	0,1989	0,9824
17.8.2012	0,0669	-0,0443	0,6059	0,0000	0,9526	0,0728	-0,0533	0,3243	0,0783	-0,1013	0,6126	0,9952
24.8.2012	0,0663	-0,0458	0,5763	0,0000	0,9541	0,0742	-0,0562	0,5909	0,2284	-0,2358	0,7093	0,9768

Table 2: t-statistics for difference between Nelson-Siegel and Svensson models' determination coefficients

	T-test for Independent Samples (krivulje prinosa statistica (B2:AV48)) Note: Variables were treated as independent samples										
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
N-S vs. S	0,8894	0,9336	-2,798	92	0,00627	47	47	0,0837	0,0689	1,4744	0,1918

7. CONCLUSION

In this paper two most used parametric models for yield curve estimation: Nelson-Siegel and Svensson model are theoretically reviewed and empirically tested on Croatian financial market. The aim was to compare results and to carry out the best fitting model for yield curve estimation in the specific market conditions with low volume, illiquidity and small number of traded securities. The yield curves are estimated based on weekly data from 7th October 2011 to 24th August 2012 using both Nelson-Siegel and Svensson model. Based on empirical results on parameters, determination coefficients and t-statistics it can be concluded that, unexpectedly, Svensson model fits better to the data and provides a more accurate yield curve on Croatian financial market. The resulting yield curves are for both models very similar, with gaps in the short term and an increase in the long time horizon.

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