An empirical econometric model for the Mexican target rate and its application to determine the interest rate curve

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Abstract

The term structure of interest rates has been a field of intense research both from the theoretical point of view as well as from the purely applied point of view. We propose in this work a novel approach to model empirically the Target Rate that Banco de México sets as part of their monetary policy using a difference of two Poisson distributions in terms of public data: the monetary decisions taken by the Federal Reserve, the exchange rate, the inflation rate and its expectation, and the economic growth results and expectations. We apply later this rate to determine with excellent statistical significance, the short-term rates and then, using it together with the ratio of public spending without financial costs to GDP, the corresponding behavior of mid-term rates also with a very good significance.

Keywords: econometric modeling; monetary policy; term structure of interest rates; fixed income securities. *JEL classification:* C51, E52, E43, G12.

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Estimación de la tasa objetivo a través de un modelo econométrico empírico y su aplicación para estimar la curva de la tasa de interés

Resumen

La estructura temporal de la tasa de interés ha sido un campo de intenso estudio tanto desde el punto de vista teórico como del práctico para lograr su estimación. En este trabajo se propone una aproximación novedosa para modelar empíricamente la Tasa Objetivo que el Banco de México fija como parte de su mandato de política monetaria, usando la diferencia de dos distribuciones de Poisson en términos de datos accesibles a todo el público: las decisiones de la Reserva Federal de los EU., el tipo de cambio, los resultados y las expectativas de inflación y las expectativas y los resultados de crecimiento del PIB. Después utilizamos esta tasa para determinar con excelente significancia estadística las tasas de corto plazo y después, junto con la razón de gasto gubernamental sin costos financieros a PIB, las tasas de mediano plazo.

Palabras clave: modelación econométrica; política monetaria; estructura temporal de la tasa de interés; bonos gubernamentales. *Clasificación JEL*: C51, E52, E43, G12.

1. Introduction

According to (Banco de México, Política Monetaria, 2020) the central Bank has as its top priority to maintain the stability of the purchasing power of the Mexican Peso. To achieve this objective, starting on January 2008, Banco de México adopted as its operational objective the one-day Interbank Interest Rate (Target Rate).

With this operational objective, Banco de México injects or withdraws daily the missing or extra liquidity of the system through Open Market Operations (liquidity auctions). The rates at which surpluses in checking accounts are paid is zero while overdrafts are charged at

twice the Target Rate for one-day bank funding.

By using the target rate for collecting overdrafts and as the basis for the Open Market Operations, Banco de México provides incentives for the funding operations between banks being carried out at rates close to that Target Rate. The operational Target Interest Rate has several advantages:

- Facilitates understanding of monetary policy actions and their effectiveness.
- Provides greater stability to short-term interest rates and greater relevance of monetary policy over the entire Rate Curve.
- It makes the instrumentation of monetary policy in a similar manner as several of the most important central banks in the world.

This Target Rate is the basic building block to determine the Interest Rate Curve, so it is very relevant to understand which factors are the most important in determining this rate. To this end, we analyzed all the minutes from Banco de México (Banco de México, Minutas, 2020) in order to determine which variables are the most relevant to the Governing Board to raise, keep, or lower the Target Rate.

From the information provided by the minutes we determined that there is a group of economic and financial data that influence the decisions of the Governing Board heavier than others, namely: the decisions of the Federal Reserve to raise or lower their rate, the exchange rate Mexican Peso-Dollar, the inflation data and expectations, the GDP growth data and expectations, and the market volatility.

Since 1999, Banxico surveys a group of analysts from Financial Institutions as well as private Consulting Firms about their expectations of several economic variables and publishes every month the results of this survey in the "Encuesta sobre las Expectativas de los Especialistas en Economía del Sector Privado". Starting in April 2019, Banxico publishes the list of Institutions which are surveyed.¹ One of the surprising results we found in this work is that, in our model, the Governing Board weighs as much the results of these surveys as the actual data, or even more in some cases.

Since the surveys are made to actual teams of analysts and then evaluated by the board, as mentioned in (Shefrin, 2002), the decisions taken could show some heuristic-driven bias, for example, representativeness, overconfidence, or gambler's fallacy. The second theme that could arise is frame dependence, for example, loss aversion/realization, mental accounting, or money illusion. It would be very interesting to analyze if there is evidence that such possible biases arise.

¹ In April 2019 the following list was published: Action Economics; Banco Actinver S. A.; Bank of America Merrill Lynch; Banorte Grupo Financiero; Barclays; BBVA-Bancomer; BNP Paribas; Bursamétrica Management S. A. de C. V.; BX+; Capital Economics; Centro de Análisis e Investigación Económica; Centro de Estudios Económicos del Sector Privado A. C.; CIBanco; Citibanamex; Consejería Bursátil; Consultores Económicos Especializados; Consultores Internacionales; Credit Suisse México; Deutsche Bank; Epicurus Investments; Evercore ISI México; Finamex Casa de Bolsa; Grupo de Economistas y Asociados; Harbor Intelligence; HSBC; IHS Markit; Invex Grupo Financiero; Itaú Asset Management; Itaú Unibanco; JP Morgan; Monex Grupo Financiero; Morgan Stanley; Natixis; Raúl A. Feliz y Asociados; Santander Grupo Financiero; Scotiabank Grupo Financiero; Valmex; Vector Casa de Bolsa; y Prognosis Economía, Finanzas e Inversiones, S.C..}

As mentioned before, the Target Rate mechanism gives the market enough incentives so that the funding operations among banks are carried out at rates close to the Target. This in turn, given the liquidity of short and mid-term Government Bonds (CETES) and the easiness of their use in funding operations (repo transactions for instance), make the rates of this instruments also very closely determined by the Target Rate. However, the rates of longer -term Government instruments are influenced by some other factors that are not directly related to the Target Rate, like fiscal and macroeconomic balances and trends.

With the intention of providing a useful tool to forecast the Target Rate and to analyze the weight of the different variables in the determination of a rate hike or a rate cut, in this paper we propose a novel econometric model where the economic and financial factors mentioned above enter to determine the intensity of a Poisson distribution for the raise and another set of economic and financial factors are considered to define the intensity of another Poisson distribution for the lower of the rate. This in turn is tested by fitting the shortterm CETES rates to the ones we would obtain from our model, and we give an example of the use of the combination of the estimated Target Rate with fiscal and macroeconomic data to model mid-range rates.

This paper is organized as follows. Section 2 explains the modeling of the Target Rate. Here we start by giving a short review of the literature related to the stochastic modelling of interest rates to conclude that a full theoretical model can become extremely complicated if we want to capture all the behavior that is shown in the Target Rate. After that, we explain the model proposed which is a much simpler model, not stochastic but econometric, based on the analysis of the information that Banxico publishes, both hard data and soft information coming from interviews, and we explain that this model is constructed in order to capture some specific aspects of this particular situation: that the Target Rate changes are given by discrete jumps, that the variables considered to an increase and those considered for a decrease are not the same, and that the magnitude of these positive or negative jumps are determined by the size of the variables considered. In section 3 we show the results of the optimization done to find the set of parameters in the model proposed and show that the approximation is consistent with the behavior of the decisions of the Governing Board. In section 4 we test the results given by the model using it to determine the rates of CETES showing that, for those bonds with maturities up to one year, our model fits very well the given rate (in all cases with $R^2 > 95\%$ and good model specifications). However, the power of adjustment and model specification decreases with the maturity so that for three-year bonds, after analyzing the residues, we found it necessary to incorporate another variable related to fiscal and macroeconomic data

which helped us correct the model specification and also let us obtain an $R^2 > 93\%$ in this case. Section 5 gives some conclusions to the paper as well as some directions of further study for this subject.

2. Modeling the target rate

Short-term rates have been modeled in different ways trying to capture their main behavior in such a way to be consistent with the prices of tradable bonds. Following (Brigo & Mercurio, 2006) we have that the first model that was regarded as relevant to this end was that of O. Vašiček (1977) based upon ideas of Ornstein-Uhlenbeck:

$$dr_t = k(\theta - r_t)dt + \sigma dWt$$

Where r_i is short term interest rate, θ is the long-term average, k is a regression toward the mean factor, σ is standard deviation and dWt a standard Wiener process. Such model allows for negative interest rates, which at that time was consider a mayor flaw. However, now we experience negative rates given by some mayor Central Banks which make us rethink on the validity of this type of model.

After that, another important model proposed, such that it avoids the possibility of negative interest rates, was the square root model introduced by Cox-Ingersoll-Ross (CIR) in 1985

$$dr_t = k(\theta - r_t)dt + \sigma \sqrt{r_t} dWt$$

These models are called endogenous one-factor models with regression to the mean, where the actual market curve is a byproduct and not an input for the model, and they contain just one source of randomness. Unfortunately, this type of models fails to capture adequately all forms that actual market curves present.

With the idea of obtaining better approximations to the actual curve, after these, many models have been proposed: exogenous (with time variable parameters that incorporate actual market data), multi-factor models (two and three-factor models, for instance) with more independent sources of stochasticity, models that incorporate jumps, models with stochastic volatility, etc.

In particular, models that incorporate jumps have proved to be very relevant, since it has been well documented, for instance in (Nuñez Mora & Lorenzo Valdés, 2008) and in (Albanese & Trovato, 2007), that jumps in the short-term part of the interest rate curve cannot be overlooked. As we will see later in this work, most of the jumps that the short-term part of the curve show, reflect the jumps coming from monetary policy.

One of such models that incorporate jumps is the so called JCIR, which is based on the CIR model with the addition of a pure jump process with intensity α >0 and size determined by some distribution π on \mathbb{R}^+ :

$$dr = k_1(\theta_1 - r)dt + \sigma\sqrt{r}dW_{1,t} + dJ_t$$

Additionaly, (Kim & Wright, 2016) proposed recently an affine model of three factors, free of arbitrage, where jumps can occur in each of the factors and not only for the short-term rates as previous models suggest. These jumps can occur at known moments on time, but their magnitude is random. They apply this model to the US rate curve and the given events they consider are the publication of employment data. An analysis of the affine models as well as Ornstein-Uhlenbeck type models in a computational approach is developed in (Osterlee & Grzelak, 2020).

In the Mexican case, the Monetary Policy decisions are taken most months in specific dates that are published at previous year's end. On those days, the Governing Board take the decision to raise, maintain or decrease the Target Rate and if the decision is to raise it or to lower it, they also determine the amount which always comes in multiples of a quarter interest point. One of the few models that incorporate monetary policy in the modeling of the interest rate is that given by (Albanese & Trovato, 2007). They propose a model that includes asymmetric jumps and they assume both, the drift and volatility, are stochastic.

$$dL_t = \mu_{a_t}(L_t)dt + \sigma_{b_t}(L_t)dW_t + dJ_t$$

where W_t is Brownian, and drift and volatility are determined by processes a_t and b_t respectively, which allows the model to adopt the most usual forms the interest rate curve shows (but not all, in particular, not humped yield curve shapes as they mention in their work). Although very interesting, as mentioned in the introduction, it fails to capture all the elements that the Target Rate reflects, not incorporating information about inflation and growth, for example.

With this in mind, during the rest of this work we will stay away from the stochastic differential equation modeling, and propose an econometric model, trying to capture only the behavior seen on the Target Rate.

We will consider that the Target Rate for the *n*th month, R_n , is given by

$$R_n = R_{n-1} + .25C_n$$

with C_n being a discrete random variable with values on the integers and which responds to a group of external variables.

After analyzing the minutes of Monetary Policy decisions, Banco de México (Banco de México, Minutas, 2020), we realized that the rational to raise or to lower the Target Rate respond to different factors. Since the main mandate of the central bank is to maintain the stability of the purchasing power of the Mexican Peso, and standard monetary policy teach us that higher interest rates help curve inflation, the board first looks at conditions that can affect inflation to determine if a hike is needed. In case these factors are under control, then they look at factors that affect growth to determine if there is a need to lower the rate to help boost growing. After this finding, we propose to consider $C_n = U_n D_n$ with both U_n and D_n being non-negative integer valued random variables depending on two different sets of external variables. We also noted that the probability of a raise is lower than a probability of not rising the rate, and even more, the probability of a two-fold raise is lower than that of a one-fold raise and higher than a three-fold raise, and so on. Also, for the decreases, the probability of a decrease is lower than the probability to not lower the rate and the probability of a two-fold decrease is lower than that of a one-fold decrease, and so on. Therefore, we conclude that this behavior is well captured by two Poisson distributions, one corresponding to U_n and another one corresponding to D_n given that the second one is restricted to be non-zero only if the first one is zero (hence being non independent.)

As we know, a Poisson distribution is determined by its intensity. We call λ_n^U the intensity corresponding to U_n and λ_n^D the one corresponding to D_n . Since intensities are necessarily positive valued, we consider instead of λ 's the variables μ so that:

$$\lambda_n^U = e^{\mu_n^U}$$

and the same for *D*.

As it is well known, given a Poisson distribution *X* with intensity λ , the probability $P[X = k] = \frac{\lambda^k e^{-\lambda}}{k!}$, and the amount of the intensity will determine the jump with the highest probability which is exactly what one wants to capture to model the decisions of Banxico's Governing Board.

After analyzing the minutes, we noted that the variables of greatest interest to determine an increase in the Target rate were the decisions taken by the Federal Reserve, inflation, and the exchange rate with the US dollar. However, we notice that not only the actual observed values of these variables was of interest, but also their changes with respect to short and medium term values (their trends, especially with the exchange rate), and, as found to be very relevant, the inflation expectations shown by the monthly survey taken by Banxico to the private sector, as mentioned in the introduction. After analyzing how these variables are affecting the decisions, we consider the following model for the natural logarithm of the intensity:

$$\mu_n^U = \alpha_0 + \alpha_1 i_{n-1} + \alpha_2 \delta_{n-1}^+ + \alpha_3 r_{n-1}^{3m} + \alpha_4 r_{n-1}^{1m} + \alpha_5 x_{n-1} + \varepsilon_n^U$$

where i_{n-1} is the rate of inflation above the target rate of 3% reported on month n-1, δ_{n-1}^+ is the amount of quarter points increased by the Fed immediately before the Governing Board decision, r_{n-1}^{3m} is the quarterly percentage change on the exchange rate with respect to the US dollar, r_{n-1}^{1m} is the monthly percentage change on the exchange rate with respect to the US dollar, and finally, x_{n-1} is the inflation rate expectation given on the Banxico survey of month n-1.

We see that the exchange rate is incorporated relative to previous values, both a quarter before and a month before. This reflects the interest given by the Board to the possibility of a transfer effect from the exchange rate to inflation. Also, we notice that it is of interest to the Board, according to our model, to consider the actual rates of inflation above target and the expectations coming from the survey. It is worth mention that before incorporating the expectation figure, the results were not as complete as they are now.

As we mentioned before, after considering that there is no risk of spiking inflation, the Board analyzes the economic growth to see if they can help dynamize the economy if needed. The variables of greatest interest to determine a decrease in the Target rate were also the decisions taken by the Federal Reserve (to lower its reference rate, in this case), relative inflation, and GDP growth. However, to capture the effect of GDP growth, we found that it was relevant to consider not actual figures, but better indicator-based data (namely the quarterly change on the IGAE index) and the growth expectation given on the Banxico survey. After analyzing how these variables are affecting the decisions, we consider the following model for the natural logarithm of the intensity:

$$\mu_{n}^{D} = \gamma_{0} + \gamma_{1}i_{n-1} + \gamma_{2}p_{n-1} + \gamma_{3}y_{n-1} + \gamma_{4}\delta_{n-1}^{-} + \varepsilon_{n}^{D}$$

where i_{n-1} is as explained before, δ_{n-1}^{-} is the amount of quarter points decreased by the Fed immediately before the Governing Board decision, p_{n-1} is the monthly change on the IGAE index for the previous month. and finally, y_{n-1} is the GDP growth expectation given on the Banxico survey of month *n*-1.

We also analyze the use of several other variables and combinations of them, such as market volatility, monetary basis, actual GDP results, and so on. However, trying to keep as much parsimony as possible for the model, we end up with these two sets of variables for the intensity of the increase and the decrease on the Target Rate which give excellent results without involving too many variables.

3. Results for the modeling of the Target Rate

As is well known, the sum of two Poisson distributions is also Poisson. However, for the difference of two such distributions, the analysis is not so simple. The distribution of the difference between two independent Poisson random variables is given by the Skellam distribution and it involves the modified Bessel function of the first kind (Karlis & Ntzoufras, 2006). Using properties of this function, maximum likelihood estimates of the parameters of the Poisson difference could be derived. However, since from construction we know that both Poisson random variables involved in our estimation are not independent, it is not easy to determine a likelihood function to maximize in our case.

To estimate the Target Rate, we considered the maximum probability obtained from each Poisson distribution to do the estimation, namely, if we found that the maximum probability was for a jump of size two, we consider that such two-fold jump happened. Using this estimation procedure, then we minimize the mean square error obtained by summing up the square of the differences between the rate the estimation provided and the actual rate. To minimize this MSE, we used a numerical evolutionary minimization process. We had to impose a series of restrictions to this minimization in order to get sensible results, especially regarding the signs that the coefficients can take. All coefficients for μ_n^D needed to be negative, while those for μ_n^U needed to be all positive, except for the first two that had to be negative.

After this minimization, we found the coefficients shown in Table 1 for the natural logs of the intensities. Since we are estimating probabilities, note that these values are among a range of values that give us the same results.

Since the evolutionary process is used to determine probabilities which in turn determine the size of the jump, all the process happens to be highly dependent on the initial values chosen (seeds), so we need to be very careful to start with some reasonable values that capture the behavior we want to model.

With the values shown on Table 1 for our coefficients, we obtained the following graph of our estimate for the Target Rate together with the actual rate:



Graph 1 Estimated TR vs actual TR

Source: self made.

We can see that our estimate captures very well the behavior of the Target Rate. It diminishes when the conditions are given to lower the rate and it increases when it is needed. Unfortunately, we can't precisely measure how well the approximation is following the actual data, given the problems we mentioned above about the nature of the estimation.

For this reason, we decided to compare our rate with short and mediumterm rates of actual tradable bonds (CETES) in order to analyze if our rate estimate is capturing in a good way the behavior of these instruments as should do the Target Rate.

4. Modeling the short and mid-range rates

To compare our estimated rate with the actual short and medium-term rates that are found on the bond market, we consider that the target rate is taken as a one day rate, so we transform the values we obtained to bond prices of different maturities considering that the price of a bond of maturity k would be $P = \frac{100}{(1 + \frac{ETR}{360})^k}$, where ETR is our estimated Target Rate. Since the bonds we are considering are CETES, we just have *k* =28,91,182,364,1092. Up to one year (*k*=364) the given rates are considered as short-term rates. For 1092 days, which correspond to 3 years, we considered that we are talking of medium-term rates. As we will show shortly, the behavior of medium-term rates differs consistently with the one that short-term rates follow.

Below we show the linear regressions for different maturities together with the trend line obtained and the value of R^2 for each of the maturities.



Graph 2







Conclution. Graph 2

Source: self made.

We see that for the first four maturities (up to one year), our model captures very accurately the behavior of the Bond prices, it fits very close the given prices (with $R^2>95\%$ in all cases). Moreover, note that the coefficient of the independent variable is very close to one reflecting that the price is changing slightly away from the behavior of the estimated Target Rate. After analyzing the residues, we also found that for those four terms, the model is well specified.

However, for the fifth bond analyzed, the model fit is not as good as for the previous ones (still R^2 =88% is sufficiently large). After analyzing the residues, we found that they fail the normality assumption and the model specification tests. The coefficient found in the regression being far from one together with

the above-mentioned issues clearly indicate that an extra variable is missing in this case.

Of course, the monetary policy is set to provide incentives for the funding operations between banks being carried out at rates close to that Target Rate. Longer maturity bonds are affected by additional variables related to longer term objectives of institutional investors, among others. It is well known that for Government bonds, fiscal and macroeconomic factors affect their behavior, see for instance (Baldacci & Kumar, 2010). With this in mind, we proceeded to analyze a series of macroeconomic and fiscal variables together with the residues left after the above regression.

The graph of the residues is shown below and clearly is far from being random and normally distributed:





Source: self made.

We also graphed some of the fiscal data to see if the residues follow any of them. The graph of the 1y moving average of the ratio of Government spending before financial costs to GDP is as follows:

Graph 4 Ratio of Government spending to GDP (1y ma)



Source: self made.

We see that they exhibit similar features. After noticing this, we decided to perform a multiple regression on the price of medium-term bonds using as regressors the estimated Price obtained from the estimated Target Rate and this ratio.

After performing this regression, with the coefficients shown in table 2, we found that R^2 and adjusted R^2 were 93%, the regression as a whole had a p-value of 8.7x10-50 and, more importantly, the residues were deemed to be normally distributed with the following Quantile plot

And a Jarque Bera p-value of 0.70. It is also considered to be well specified since the Breusch-Pagan test gave a p-value of .35. It is worth to notice that the coefficient corresponding to the estimated price coming from the estimated Target Rate is again very close to one.

5. Conclusions

In this paper, we propose what we consider could be a useful tool to forecast the Target Rate and also a useful tool to analyze the weight of the different variables in the determination of a rate movement for the Target Rate given by the Governing Board of Banco de México. After analyzing the minutes given by the Board, we conclude that we had to consider different variables for a raise and for a lower of the rate. For a raise, we consider the rate of inflation, the amount the Federal Reserve increased its rate, the exchange rate, and the inflation rate expectations published on the Banxico survey. For a lower, we consider also the rate of inflation, the amount the Federal Reserve decreased its rate, the change on the IGAE index. and finally, the GDP growth expectation given on the Banxico survey, which sets up questions about the possible behavioral bias the decisions could have. We tried to keep our model as simple as possible, so we restrict ourselves to these variables since a group of additional variables analyzed didn't contribute substantially to the determination of a good fit.

These economic and financial factors mentioned above are combined linearly to determine the natural log of the intensity of one Poisson distribution for the raise and another for the lower of the rate, which are not independent. By minimizing a suitable mean square error, we determined the coefficients for each of the variables involved. This in turn was tested by fitting the shortterm CETES rates to the ones we would obtain from our model, and since we don't have a good fit for medium-term rates, we give an example of the use of the combination of the given Target Rate with fiscal and macroeconomic data to model them in a suitable way.

We decided to focus on CETES since longer-term Bonds exhibit different characteristics. However, it would be interesting to analyze those Bonds on the light of the results found to see if there are additional financial, fiscal or macroeconomic variables that get involved in the specification of their price. It would also be interesting to compare the given results with the many jobs done on the term structure of interest rates in terms of principal components, to determine if these principal components could be expressed in terms of the variables we found to be relevant to our estimation.

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Tables

Table 1

Coefficients to the natural log of the intensities of raise of the rate and to lower the rate

α_0	α_1	α2	α,	α ₄	a ₅
-4.9	-133	8.3	2	19	54
γ ₀	γ_1	γ_2	γ_3	γ_4	
-0.25	-4	-0.24	-0.8	-0.39	

Table 2

Coefficients to the multiple regression for the price of the medium-term Bond

	Coefficients	Standard error	T-Statistic	P-value
Intercept	11.6045945	2.821399289	4.113063524	8.9059E-05
Estimated price from estimated Target Rate	0.96955313	0.047356988	20.4732853	8.1116E-35
(Debt w/o Fin Costs)/GDP	298.831912	39.64835122	7.537057736	4.5247E-11