

OTDK-paper

2023

CORVINUS UNIVERSITY OF BUDAPEST
INSTITUTE OF FINANCE, ACCOUNTING AND ECONOMICS LAW



ARBITRÁZS LEHETŐSÉGEK A MAGYAR ÁLLAMPAPÍRPIACON
AZ ELMÚLT 20 ÉVBEN

ARBITRAGE POSITIONS IN THE HUNGARIAN GOVERNMENT
BOND MARKET
OVER THE LAST 20 YEARS

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Completion date: 2023. 01. 09.

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1. INTRODUCTION

Tamás Makara (2004) investigated the Hungarian government bond market to find possible arbitrage positions in the early 2000s. His empirical results showed that the Hungarian government bond market is a well-functioning market. In my research, I broaden this research as I examine a longer period, from January 1, 2003 to February 22, 2022 to see if the market was still well-functioning in the previous 20 years. I expect to find arbitrage positions, however, my research aims not only to show if it was possible to have arbitrage in this investigated period but to also find the reasons for these cases.

To recognize the arbitrage positions, I use a linear programming model for the investigated 4793 days. This is a common method used in the literature, Hodges & Schaefer (1977), Herzel (2005) and Cornuejols & Tütüncü (2006) also used simple linear programming model for finding arbitrage. My research is different from the mentioned ones, as I apply this model to the bond market, especially the Hungarian government bond market, which is a less-discovered area of arbitrage possibilities. Cornuejols & Tütüncü and Herzel are investigating the derivative market, whereas Hodges & Schaefer are focusing on the bond market, however, my aim with this paper is to actualize the used method in the current government bond market and see the reasons for possible arbitrage positions.

In my research, first I give a quick look at the Hungarian government bond market and present the used arbitrage concept. Then, I introduce the applied method, and the linear programming model and give the mathematical background of my calculations. In the next part, I show my empirical results and give some explanation about the reasons for the found possible arbitrage positions. The method and the concept of this paper are not newly developed; however, the achieved empirical results of the linear programming problem give a better view of the Hungarian government bond market in the last 20 years.

2. THEORETICAL BACKGROUND

2.1. OVERVIEW OF THE HUNGARIAN GOVERNMENT BOND MARKET

The government bond market is a crucial element of a country's budget plan. A country's government issues several securities to obtain financial resources for its daily operation, to repay government debt or for innovation projects. As these bonds are debt obligations, the government guarantees to repay the purchaser of the bonds the face value or the face value plus a coupon rate. In my research, I examine the Hungarian government bond market, as the Hungarian government is a stable, presumably existing government, and the government bonds issued in the country's own currency are usually considered risk-free.

There are two types of government securities according to their maturity: Treasury bills with a shorter maturity and Treasury bonds with a maturity of more than one year. Treasury bills are typically low-interest and lump-sum government securities that are easy to redeem, making them a short-term, but less risky investment alternative. In contrast, Treasury bonds have a maturity of 3, 5, 7, 10, 15, or 20 years, have a fixed or variable interest rate, and pay interest every 12 months. In a regular time when the yield curve is normal, the government guarantees a higher yield for the bonds held for a longer period, so the long-term Treasury bonds have a higher yield to maturity than the short-term Treasury bills.

Available government bonds include fixed and floating rate securities. In the case of floating-rate bonds, the value of the interest rate is adjusted to the rate of inflation, so the coupon rate can change typically once a year. Interest is paid semi-annually or annually. In addition, different risks affect the interest rates of the bonds: currency risk prices higher interest rates on bonds denominated in weak and uncertain currencies, and longer maturities also contribute to higher interest rates. In my calculations, I am only examining fixed-rate, HUF-denominated government securities, that have an annual payment, as the cash flows of these securities are deterministic for the future.

In Hungary, the issuance of government securities is run by the Hungarian Public Debt Management Centre (ÁKK), where primary dealers can access the securities by a public offer. The group of customers, so to call the list of primary distributors, is determined by the Hungarian state and there are currently 13 such institutions.ⁱ The auctions are held every other week on Thursdays and only primary distributors can participate in these. Investors can access available government securities through primary dealers. Primary dealers are

required to keep a record of the bid and ask prices, at which investors can trade on the secondary market. In contrast to over-the-counter trading, these prices are publicly available and binding, so they are well suited for the examination of the Hungarian government securities market. For every available security, at least three primary dealers should keep a bid and ask price.

Primary dealers are required to quote a pre-determined minimum amount of the securities that are available for sale during the quotation period, where the maximum difference between the bid and ask prices is also fixed. The largest difference between the bid and ask prices is 50 basis points, while the minimum quoted volume is 200 million HUF for the most liquid securities and 100 million HUF for the less liquid ones. ÁKK records the highest available purchase and lowest selling prices among primary distributors daily on its website. Retail and corporate bond purchases can be made through primary dealers or by over-the-counter trading. For greater transparency, my research only examines the trades available at primary distributors. (Makara, 2004)

2.2. USED CONCEPT OF ARBITRAGE

Arbitrage is a core concept of finance: a trading strategy is an arbitrage strategy if a profit is guaranteed without investing any capital. It usually arises when the efficient market theory is violated at a point. It can be either because the same securities are traded at different prices on different markets; because the spot and the forward prices are not consistent with the risk-free rate or because two securities with the same future cash-flow structure have different prices. In my case, the last point is the most relevant, as I am investigating only the Hungarian government bond market and I am not dealing with over-the-counter markets, nor with futures or forwards.

If the third point is violated, one can generate an arbitrage position by buying the cheap security and selling the expensive one at the same time. As the securities have the same coupon cash flow structure in the future, the positive income that comes from buying the cheap security can pay off the obligation, that has risen from selling the expensive one. In this way, the trader gains exactly the price difference between the two securities at the time of the transaction. However, when traders find out this opportunity, a strong supply will arise in the expensive security market, whereas in the cheap security market there will be a strong demand. This will quickly rebalance the prices of the different securities so that the market equilibrium can be restored as well. Though, there is only a slight possibility of

these events, thanks to the quick response of the profit seeker traders and the advanced IT systems the market is using.

Björk (2004) classified the arbitrages into two different types: type A and type B. Type A arbitrage is where there are no initial costs but there is a positive possibility of a profit in the future. On the other hand, in type B arbitrage, the cash flow at t_0 is positive and there is no liability in the future (Björk, 2004). In addition, Herzel (2005) differentiated the arbitrages based on the portfolio composition: in the dynamic arbitrage strategies the portfolio is actively re-balanced, while in static strategies the portfolio remains unchanged (Herzel, 2005).

In my research, I use a static arbitrage concept that is a mixture of the two types. I trade only on the initial day and realize a possible arbitrage position only if the cumulative cash flow at t_0 is overall positive. I also use a trading strategy where every bond is held until maturity to avoid the changes in market interest rates between the date of issue and maturity. My approach to arbitrage is however a broader concept compared to the type B arbitrage, as I allow to have liabilities in the future. This is a necessary change to be able to short a government bond at t_0 and not limit the possible transactions to only buying a bond that pays coupons in the future. The model is the same as Makara (2004) used when he investigated the Hungarian government bond market between 2003 and 2004. One additional change in my used arbitrage concept compared to the common methods is that I treat the bid and ask prices separately, which represents better the real conditions in the markets.

To get to the used concept, take the number of available securities, n on the Hungarian government bond market on day t . These securities have future payment or repayment of coupons at time $t_1, t_2, \dots, t_m$ where $t_1 < t_2 < \dots < t_m$. On these days there is at least one security, which has a coupon payment or repayment. The i^{th} available security at time j has a coupon payment of C_{ij} and bid and ask price of p_i^b and p_i^a . The traders can sell their securities at p_i^b , because this is the highest price a buyer is willing to pay for the instrument, and they can buy them at p_i^a , as this is the lowest price a seller is willing to accept for the same instrument. Thanks to the structure of the order book, $p_i^b \leq p_i^a$. (Makara, 2004)

If the trader is buying $x_i^a \geq 0$ and selling $x_i^b \geq 0$ amount of the i^{th} security, its cash flow at t_0 is $(p_i^b x_i^b - p_i^a x_i^a)$. For the model I assume, that the securities are infinitely divisible, so $x_i^a \in \mathbb{R}_0^+$ and $x_i^b \in \mathbb{R}_0^+$.

At t_0 the trader realizes

$$v_0 = \sum_{i=1}^n (p_i^b x_i^b - p_i^a x_i^a)$$

immediate income, and at t_j a cash flow of

$$v_j = \sum_{i=1}^n (x_i^a - x_i^b) C_{ij}.$$

If we investigate n security the cash flow of the market on that day can be given by the $(\mathbf{p}^a, \mathbf{p}^b, \mathbf{C})$ parameters, where arbitrage is possible if there are $0 \leq x_1^a, x_2^a, \dots, x_n^a$, and $0 \leq x_1^b, x_2^b, \dots, x_n^b$ amounts, where $\mathbf{v} = (v_0, v_1, \dots, v_j)' \geq 0$. This relation means that every element of $\mathbf{v}$ is non-negative and there is at least one element of $\mathbf{v}$ that is positive. (Makara, 2004)

To this point, I presented a common interpretation of arbitrage as this model does not allow v_j to be negative. This means that the trader cannot short a bond that has a payment on a day when it's the only one that has a coupon payment. For example, if a trader sells 1 unit of a government bond, that pays 6% of its face value every year, the cash flow of the trader at t_j from that security is $-x_i^b C_{ij}$, so the trader has an obligation to pay this amount back. In the used definition this cannot happen, because the v_j on that day would be negative.

To handle this change, Makara (2004) introduced a broader interpretation of arbitrage, which allows having obligations in the future. If a trader can gain a positive income of $v_1 = 1$ at t_1 and can invest that amount with a positive interest rate, at t_2 he can certainly repay a $v_2 = -1$ obligation. This allows them to sell securities at t_0 even if they have a coupon re-payment time when there are no other payments of other securities. In the following, I change the previously presented arbitrage concept as so:

A possible arbitrage position occurs with the $(\mathbf{p}^a, \mathbf{p}^b, \mathbf{C})$ parameters if $0 \leq x_1^a, x_2^a, \dots, x_n^a$, and $0 \leq x_1^b, x_2^b, \dots, x_n^b$ exist, where

$$\mathbf{k} = (k_0, k_1, \dots, k_j)' \geq 0 \text{ and } k_j = \sum_{s=0}^j v_s.$$

So, this new definition allows to have negative future cash flow days, the criterion is to have a non-negative cumulative cash flow for all times. (Makara, 2004)

Take, for example, two bonds whose prices and payments are as follows:

Table 1 : Example for different arbitrage definitions

	Bid Price	Ask Price	t₁	t₂	t₃	t₄
A	98	99	3		103	
B	99	100		2		102

(Source: own elaboration)

It is clear that the two bonds are mispriced, as bond A pays more based on the pay-out, but bond B is still moving at a higher price. In such a situation, according to the classical definition, there is no possibility of arbitrage. If we buy from the cheaper, bond A and sell from the more expensive, bond B, the future cash flow will be as follows (0, +3, -2, +103, -102). According to the classical definition, we cannot have any obligation in the future, meaning we cannot sell bond B. However, according to the extended arbitrage definition, it is possible to realize a negative cash flow in the future if the cumulative cash flow remains positive during the entire pay-period. The cumulative cash flow for the example functions is as follows (0, +3, +1, +104, +2). That is in fact a possible arbitrage position.

3. METHOD

3.1. LINEAR PROGRAMMING MODEL

To see if an arbitrage position exists in the Hungarian government bond market, I used a simple linear programming model for each of the 4793 investigated days. The linear programming model is widely used in the literature, Ronn (1987) and McLeod (1998) also used this method. In my research, I investigate the Hungarian government bond market, where the different securities have riskless cash flows in the future. This allows the use of the simplex method to the problem, where the goal is to find $x_1^a, x_2^a, \dots, x_n^a$ and $x_1^b, x_2^b, \dots, x_n^b$ variables that

$$\max \sum_{j=0}^m k_j$$

subject to the following constraints:

$$0 \leq x_1^a, x_2^a, \dots, x_n^a \leq 1$$

$$0 \leq x_1^b, x_2^b, \dots, x_n^b \leq 1$$

$$\text{And } 0 \leq k_j$$

The linear programming model will always have a possible solution, where $x_1^a, x_2^a, \dots, x_n^a$ and $x_1^b, x_2^b, \dots, x_n^b$ are all 0, so the trader does not buy or sell any securities. In this solution the max of the linear problem's objective function is exactly 0. However, to find an arbitrage position the linear programming model's objective function must be positive.

The model is easy to understand with 2 or 3 variables, but for one day, the number of available government bonds is approximately 25, so it is better to see the model in an augmented form. As we take the $(\mathbf{p}^a, \mathbf{p}^b, \mathbf{C})$ parameters, which can fully describe the available market in one moment, the linear programming problem can be described with the following vector formulas:

$$\mathbf{P} = \begin{bmatrix} p_1^b \\ p_2^b \\ \dots \\ p_n^b \\ -p_1^a \\ -p_2^a \\ \dots \\ -p_n^a \end{bmatrix} \quad \mathbf{C}_j = \begin{bmatrix} -C_{1j} \\ -C_{2j} \\ \vdots \\ -C_{nj} \\ C_{1j} \\ C_{2j} \\ \vdots \\ C_{nj} \end{bmatrix} \quad \mathbf{X} = \begin{bmatrix} x_1^b \\ x_2^b \\ \dots \\ x_n^b \\ x_1^a \\ x_2^a \\ \dots \\ x_n^a \end{bmatrix}$$

The problem is:

$$\max \left[(m+1) * \mathbf{P} + \sum_{j=1}^m ((m+1-j) * \mathbf{C}_j) \right]^T * \mathbf{X}$$

With the constraints of:

$$0 \leq \mathbf{X} \leq 1$$

And

$$0 < (\mathbf{P} + \sum_{i=0}^j \mathbf{C}_i)^T * \mathbf{X} \text{ where } j = 0, 1, 2, \dots, m \text{ and } \mathbf{C}_0 = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

The value of the objective function with the optimal solution to the linear problem is a non-negative rational number. If this number is higher than 0, it shows that a possible arbitrage position exists, however the value of the solution does not have any meaning in our case. A profit of a possible arbitrage position is infinite, as by investing more, a higher profit is achievable, so in my research, I only use the solutions as a binary variable. If an upper constraint condition was not imposed on the x variables when specifying the linear programming problem, they could be an infinite value in the case of a possible solution, so even if there were a possible set of solutions, there would be no single optimal solution.

Where the solution for the problem is 0, it is not arbitrage, where it is not 0 it is a possible arbitrage position. To get a whole picture of the Hungarian government bond market I repeated this model for every day where the ÁKK quoted bid and ask prices, which was 4793 days in total.

3.2. USED DATA

I used the lowest daily buying and highest daily selling prices available on the ÁKK website for my research. These data are historically available, so the scope of my research is the dates between January 1, 2003, and February 22, 2022.

Primary dealers record the trading prices of the currently available government securities for each business day during the mandatory quotation period, of which the ÁKK only communicates the best daily prices. It is worth noting that according to the reporting policy of the ÁKK, the quotation period extends from the date of issue of new government securities only to 90 days before maturity, so investors can't buy or sell government securities within 3 months before maturity through the primary dealers.

From the available data, I created a vector containing daily bid and ask prices based on the above and produced a matrix of payments, in which I examined only the days on which at least one bond has an interest payment date. A Treasury bill is paid in a lump sum at maturity, meaning that its coupon cash flow only shows as 100 in one future day. On the other hand, Treasury bonds pay interest annually and then repay the nominal value plus interest on the date of maturity. For example, the cash flow of a 6-year government bond coupon with a 6% interest rate would be as follows (6, 6, 6, 6, 106). Since in most cases, the issue and maturity dates within a year do not match each other, at the very first year the bond does not pay exactly 6%.

According to the applied practice of the ÁKK, if more than 3 months (90 days) elapse between the first interest payment and the issue, the time-proportionate fraction of the interest is paid on the first interest payment according to the following formula:

$$c_1 = \frac{d_1 - d_0}{d_s} \times c$$

where

c the interest rate of the bond

c_1 is the interest paid on the first interest payment

d_s is the number of days in the calendar year of issue

d_1 is the date of the first interest payment

d_0 is the date of issue

The coupon cash flow of the example bond which has exactly 6 months between the issuance and the first interest payment is the following (3, 6, 6, 6, 106). However, if the first interest payment is made within 3 months, this part will be credited to the second interest payment in addition to the full interest for that year. Thus, if the example bond had a payment date exactly 2 months after the issuance, the coupon cash flow of it would be as follows (0, 7, 6, 6, 106). To achieve the correct empirical results, I also used these modifications in the structure of the model.

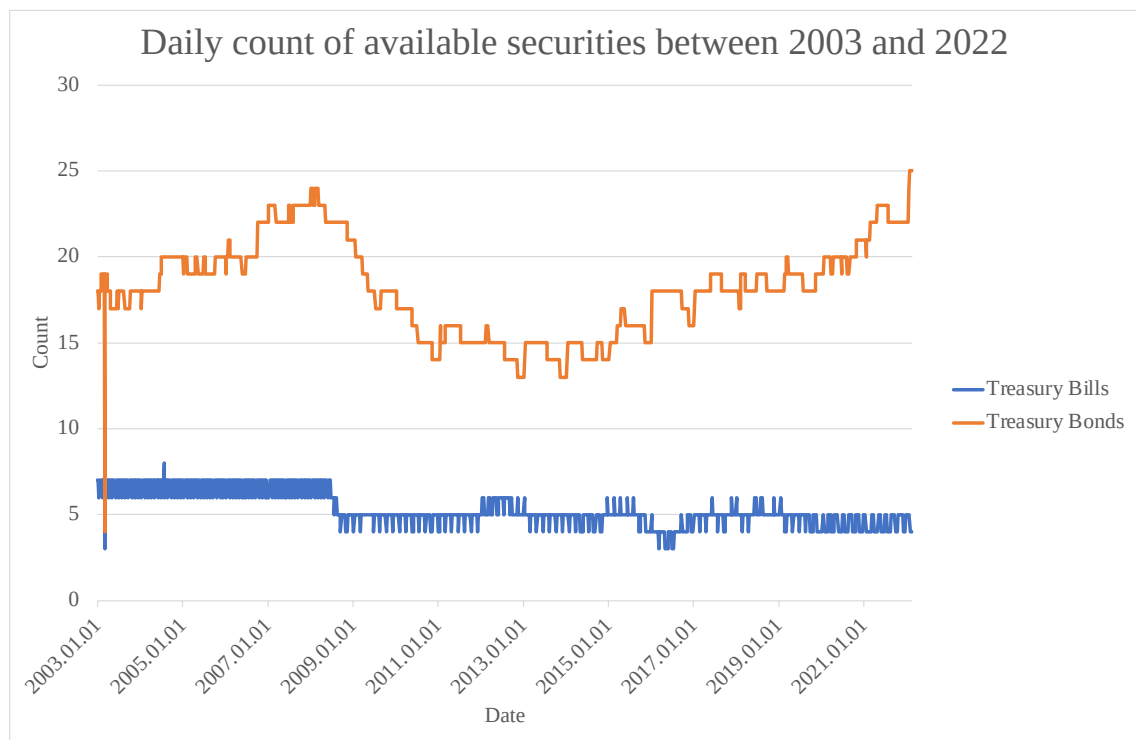
For the available bid and ask prices from the ÁKK, the given prices must be adjusted by the value of the interest accrued until the purchase. In the case of interest-bearing government bonds, the bondholder is entitled to the interest, so the seller of the bond must be compensated with the value of the interest accrued up to the date of sale.

The rate of accrued interest is also recorded by ÁKK, however, to simulate real transactions, the bid and ask prices provided by primary distributors must be adjusted by the rate of accrued interest. If we buy a bond, we will have to compensate the original owner of the bond with the interest due to him, so the price paid will be the sale price plus the value of the accrued interest. Otherwise, if we sell a bond, the interest accrued until the transaction will still be due to us, so the price received for the bond will be the purchase price plus the value of the accrued interest.

For my calculations to be as accurate as possible and to simulate the real market conditions, these were essential changes to the publicly available historical data, provided by the ÁKK.

In my research, I examined a total of 245 government securities, of which 79 were government bonds and 166 were Treasury bills. Figure 1 shows the daily number of available securities of these two types.

Figure 1 Count of available securities daily between 2003.01.01 and 2022.02.22



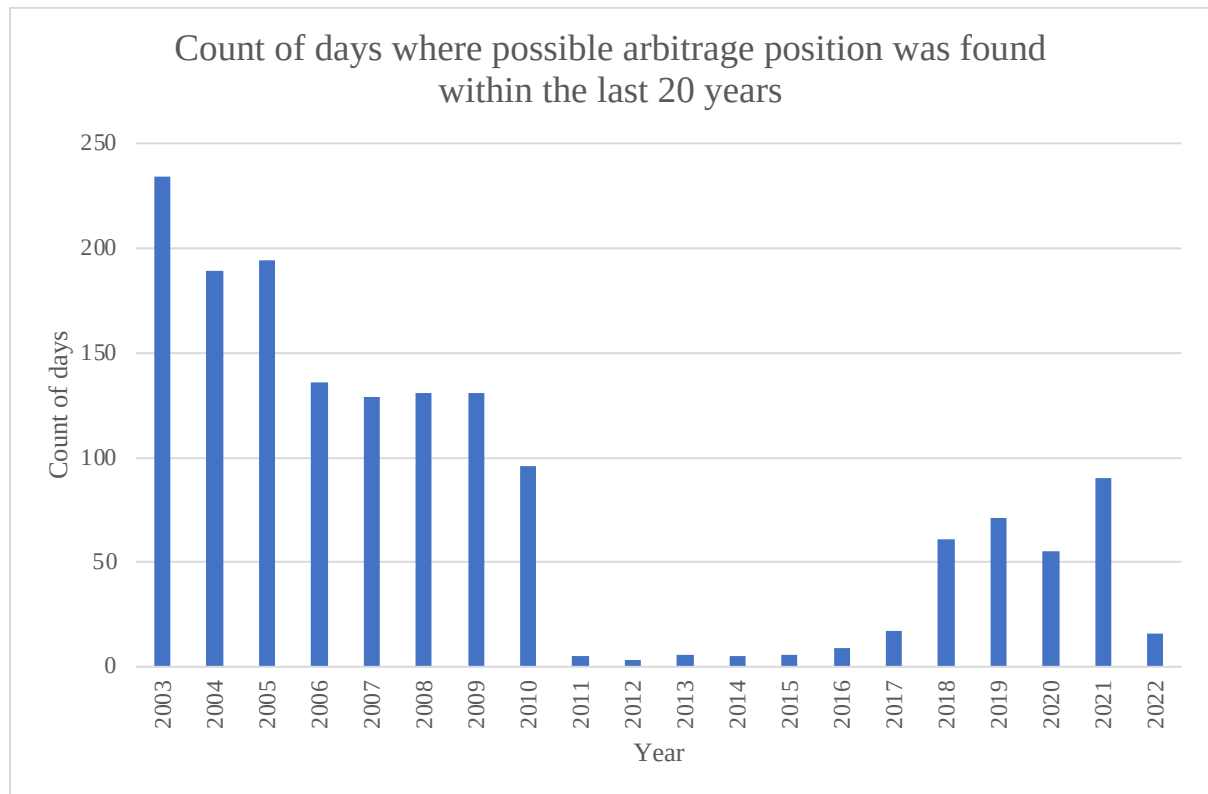
(Source: own elaboration)

4. RESULTS

In my research, I examined 4793 trading days between January 1, 2003, and February 22, 2022. The ÁKK quoted the highest bid and lowest ask prices for every available security at the Hungarian government bond market daily. Out of all the days examined, I found the possibility of arbitrage in 1584 cases according to the definition I used. This is 33.05% of the cases.

If we look at the distribution of the arbitrage opportunities found in the studied period, it is striking that in the first 3 years I found about 200 days per year and in the next 5 years around 100 days per year.

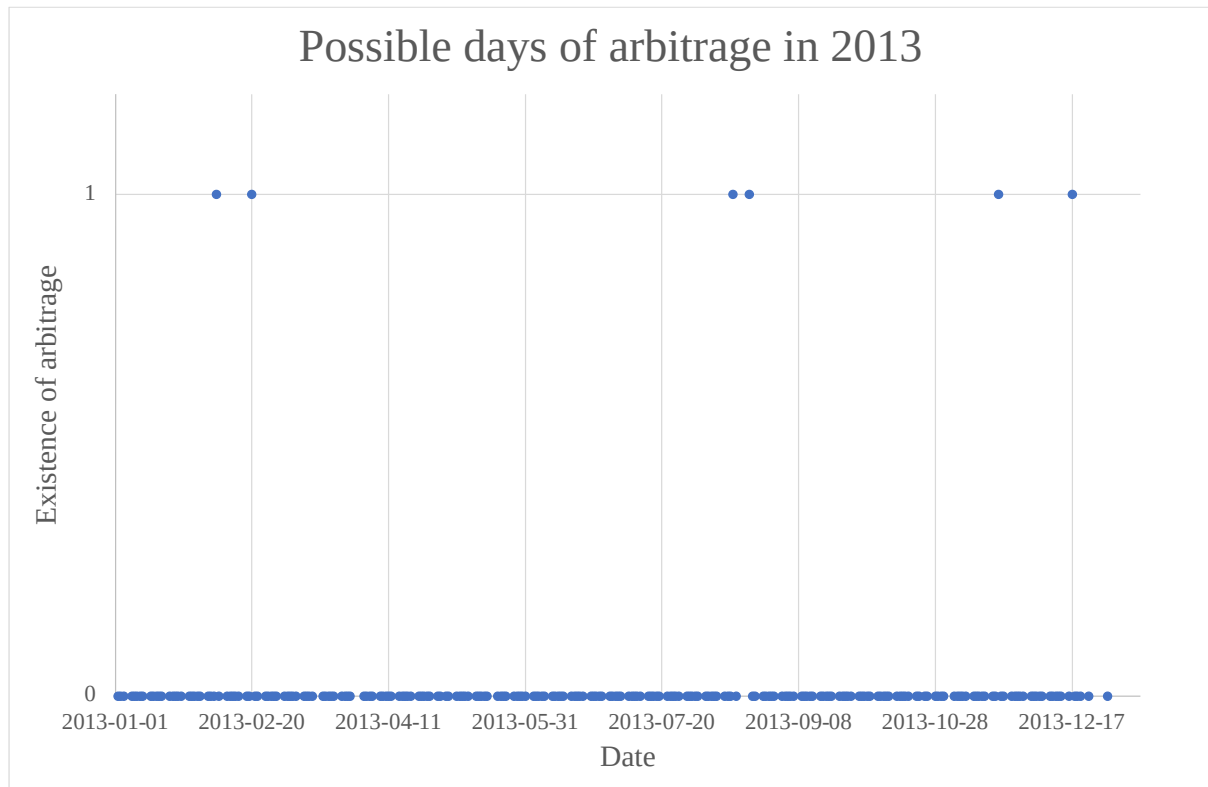
Figure 2 The count of days where a possible arbitrage position was found between 2003 and 2022



(Source: own elaboration)

There have been far fewer opportunities for arbitrage since 2010, which is in line with our expectations that there is no lasting opportunity for arbitrage in a well-functioning market. For example, if we look at the days found in 2013, we can see that although there were 6 opportunities for arbitrage, these opportunities were not permanent.

Figure 3 The days when an arbitrage strategy was possible in 2003

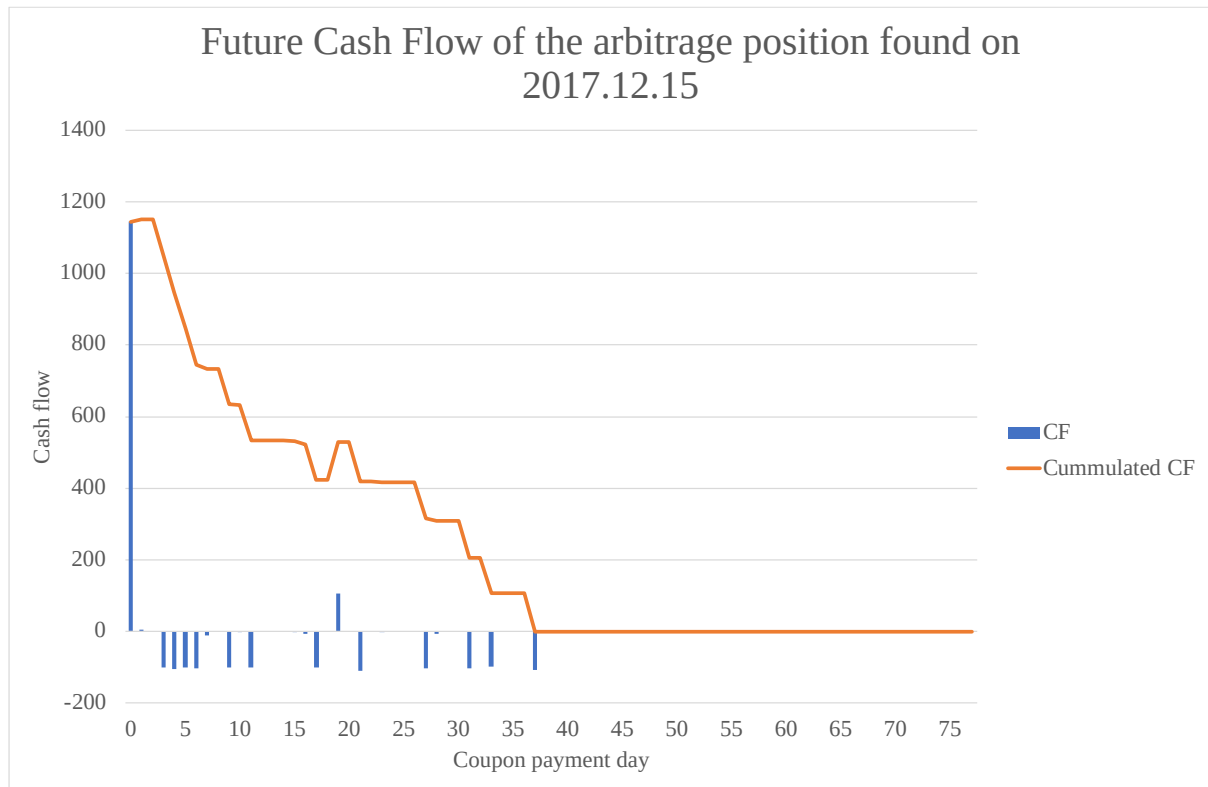


(Source: own elaboration)

However, looking at the results over the whole period, it is no longer true that the arbitrage positions were only temporary. Due to the high number of opportunities, the arbitrage usually lasted for weeks. The number and density of the solutions found would allow us to conclude that the Hungarian government securities market is inefficient. However, I also examined the individual solution days for a broader interpretation of the result.

In 2017, out of the 251 trading days examined, there was a total of 17 opportunities for arbitrage according to the definition I used. It is interesting to note that 10 of the 17 possible arbitrages occurred in the days after December 14, which continues even in the first days of the following year, so the arbitrage opportunity found here stood up for a total of 24 trading days. For a deeper examination of the result, consider, for example, December 15, 2017, where future cash flows are as follows.

Figure 4 The future cash flows of the possible arbitrage position found on 2017.12.15



(Source: own elaboration)

Figure 4 shows that future cash flows on December 15, 2017 are negative for several days, which is not allowed by the classical arbitrage definition. If we had examined this day with the classical concept of arbitrage, the linear programming problem studied would not have found a possible solution, which means, there was no arbitrage on this day.

The figure also shows what the cumulative value of cash flows will look like in the future. In my research, I set a limiting condition for this value in the linear programming problem, which corresponds to the extended arbitrage concept presented earlier. According to the definition used, arbitrage can also be considered, if we can be sure that the future obligation can be paid from the proceeds of the transaction.

The very high initial cash flow on December 15, 2017 will allow us to repay our obligations in the future, and if we can invest this initial amount at any positive interest rate following the payments, a guaranteed profit will be generated with the transaction. Because no initial investment is required to make a profit, the amount of profit available depends only on the value of the initial trade. If we give twice as much and buy twice as much of the government securities in the optimal solution for linear programming, we will have exactly

twice as much profit. Thus, the arbitrage opportunity found is indeed a possible opportunity to realize a guaranteed profit without any investment.

Therefore, the arbitrage opportunities found in the current market do not explain the efficiency of the market but the difference in the definition of used arbitrage. According to the classical definition of arbitrage, there would not have been so many options, as it would not allow negative cash flow at any future date. I found a large number of and more importantly lasting arbitrage options, which shows that arbitrage by the extended concept is no longer corrected by the market.

Furthermore, if we compare my results with the results of Makara's research written in 2004, we can also see a difference in the number of arbitrage opportunities found. Tamás Makara examined the period between June 13, 2002, and April 27, 2004, in which he found only 4 days where a possible arbitrage was available according to the extended definition of arbitrage. In his research, Makara also examined the best daily bid and ask prices available at ÁKK. Today, the historical data are only public on the ÁKK from January 1, 2003 and an important difference is that they are published only once a day.

Examining my results, it is striking that between 2003 and 2010 I found a significant number of days of arbitrage. For the first 3 years, there was a possibility of arbitrage almost every day, which is a surprising result compared to Makara's article. However, if we look at the solution of the model and the frequency of the results in the years after 2010, the linear programming problem has found an optimal solution on far fewer occasions. The differences between the nearly 20 years since the article was written and the amount of data available during the period, we both studied (January 1, 2003 - April 27, 2004) suggest that the currently publicly available data do not accurately reflect market conditions at that time.

Of course, if we remove this outlier period concerning a data error, the number of possible arbitrage positions in the period under review, from 2011 onwards is still significant. This should not be a problem, as arbitrage positions can occur even in efficient markets, but what is more important, that the market can correct arbitrage positions immediately. During the remaining part of the studied period, this was not true as in 83.4% of the possible cases, arbitrage was available for at least 2 following days. Thus, the result still shows that the Hungarian government securities market is operating efficiently, but the concept of arbitrage I use is different from the one used in practice.

5. DISCUSSION

Examining the results, I concluded that although the Hungarian government bond market is an efficient market, it still has the potential for arbitrage. This is possible because the definition of arbitrage I use is a more permissive interpretation of the commonly used concept of arbitrage. So, the research shows that the market is unable to recognize and correct this type of arbitrage. Based on the results of the research, this is a weak part of the Hungarian government bond market, which, if anyone recognizes, can achieve a guaranteed profit without any initial investment of money.

As a further reflection of the research, it would be worthwhile to examine whether the government bond markets of other countries recognize these arbitrage opportunities, or whether each market can only correct the classical arbitrage. The Hungarian government securities market operates in a structure like the bond markets of the developed countries, which means only primary dealers can participate in state auctions, and further corporate and retail trading operates through these primary dealers. If the examined country also has a central data collection platform, where we can get a current view of the position of the government bond market, the model used in my research can be transferred easily. It would be worthwhile to examine if there is any other country that can correct the arbitrage in this broad concept and to see if they use any market restraint or government intervention to achieve this.

In addition, the model used in my research could also be extended to include the transaction costs not derived from the difference between the bid and ask price. Transaction costs are significant items in real trading, which are costs such as supervision fees, stock exchange fees, and the cost of borrowing security in the case of a short position. If historical data were available on these cost items, they would also be easily added to the model I examined. Examining the arbitrage opportunities found one by one, it can be determined whether this is indeed an existing arbitrage or whether the profits are in fact lower than the transaction costs.

My research examined the arbitrage opportunities available in the Hungarian government bond market in the last 20 years from a new perspective. With the help of the linear programming model, I produced new empirical results, which gave a new picture of the behaviour of the Hungarian government bond market. Further expansion of the research in the suggested ways would hold interesting additional results.

BIBLIOGRAPHY

- Tamás, M. (2004). Arbitrázslehetőségek vizsgálata a magyar állampapírpiacon. *Sigma*, XXXV., 3-4.
- Schaefer, S. M., & Hodges, S. D. (1977). A Model for Bond Portfolio Improvement. *The Journal of Financial and Quantitative Analysis*, Vol. 12, No. 2, 243-260.
- Herzel, S. (2005). Arbitrage opportunities on derivatives: a linear programming approach. *Dynamics of Continuous, Discrete and Impulsive Systems, Series B: Applications & Algorithms* 12, 589-606.
- Cornuejols, G., & Tütüncü, R. (2006). *Optimization Methods in Finance*. Pittsburg: Cambridge University Press.
- Björk, T. (2004). *Arbitrage Theory in Continuous Time*. Oxford University Press.
- Ronn, E. I. (1987). A New Linear Programming Approach to Bond Portfolio Management. *The Journal of Financial and Quantitative Analysis*, Vol. 22, No. 4, 439-466.
- McLeod, D. J. (1989). *A linear programming approach to trading in bond-based securities*. Sydney: The Univesrity of New South Wales.
- Balogh, C., & Kóczán, G. (2008). *Állampapírok másodpiaci kereskedési infrastruktúrája*. Budapest: Magyar Nemzeti Bank.

APPENDIX

1.APPENDIX: PRIMARY DEALERS

ⁱ Table 1: List of Primary dealers of Hungarian government securities

The primary dealers of the Hungarian Government Bond Market		
Primary Dealer	Adress	Page
BNP Paribas SA	16 Boulevard des Italiens, 75009 Paris, France	http://www.bnpparibas.com
CIB Bank Zrt.	1027 Budapest, Medve utca 4-14.	http://www.cib.hu
Citibank Europe plc. Magyarországi Fióktelepe	1133 Budapest, Váci út 80. Promenade Garden	http://www.citibank.hu
Deutsche Bank AG	Taunusanlage 12, 60325 Frankfurt am Main, Germany	http://www.db.com
Erste Befektetési Zrt.	1138 Budapest, Népfürdő utca 24-26.	http://www.erstebroker.hu
Goldman Sachs Bank Europe SE	Marienturm, Taunusanlage 9-10, D-60329 Frankfurt am Main, Germany	http://www.gs.com
ING Bank N.V. Magyarországi Fióktelepe	1068 Budapest, Dózsa György út 84/B	http://www.ingbank.hu
J.P. Morgan SE	Taunustor 1, D-60310 Frankfurt am Main, Germany	http://www.jpmorgan.com
K&H Bank Zrt.	1095 Budapest, Lechner Ödön fasor 9.	http://www.khb.hu
MKB Bank Nyrt.	1056 Budapest, Váci utca 38.	http://www.mkb.hu
OTP Bank Nyrt.	1131 Budapest, Babér utca 9.	http://www.otpbank.hu
Raiffeisen Bank Zrt.	1054 Budapest, Akadémia utca 6.	http://www.raiffeisen.hu
UniCredit Bank Hungary Zrt.	1054 Budapest, Szabadság tér 5-6.	http://www.unicreditbank.hu

Source: The official site of the Hungarian Public Debt Management Centre (ÁKK),
<https://www.akk.hu/allampapir-forgalmazas/elsodleges-forgalmazok>,
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