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Financial Sustainability - Game Theory Analysis of Options Approach for a Czech Bank

*Karel Janda– Petr Marek**

Abstract

This paper applies a model of bank run based on game theory analysis of options to the real world case of the Czech retail bank Air Bank a. s. We discuss the main factors affecting the susceptibility of Czech banks to bank run. We estimate the equity value which triggers bank run for Air Bank's a. s. clients. We also simulate a possible bank run, using a liquidity stress test, which is similar to stress tests used by some European supervisory authorities. We provide alternative estimates of critical value of bank's equity after the attainment of which depositors withdraw their deposits and by doing so trigger a bank run.

Key Words: Bank run, liquidity, game theory, option pricing

JEL codes: C72, G01, G21

1. Introduction

Bank runs have been and still remain one of threats to the stability of the financial system, which was one of defining feature of the global economic crisis in 2008 (Bernanke, 2010). This paper applies a model of bank run, introduced by Ziegler (2004) to the real world case of the Czech bank Air Bank a. s. We first estimate the equity value, which triggers bank run for Air Bank's a. s. clients. Then we simulate a possible bank run, using a liquidity stress test, which is similar to stress tests used by some European supervisory authorities.

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In our case study we focus on Czech retail bank Air Bank because the computation of equity value triggering a bank run is well suited for retail banks, which fund their business from deposits collected from individual depositors. Air Bank complies with this requirement, since deposits comprise 98 % of bank's liabilities as it is depicted in a simplified balance sheet from the third quarter of 2019 below in Table 1.

Tab. 1: Air Bank's balance sheet to 30.9.2019

Air Bank's balance sheet	
Liquid assets (24 bn. CZK)	Deposits (104 bn. CZK)
Loans (88 bn. CZK)	
	Equity (8,8 bn. CZK)
Total 115 bn. CZK	Total 115 bn. CZK

Source: <https://www.airbank.cz/file-download/informace-o-air-bank-k-30-9-2019-cast-1.xlsx>

In order to compute equity value triggering bank run we need to know an initial investment made by shareholders when founding the bank. Due to this requirement, it is very convenient to use Air Bank, because the bank was founded in 2011 and all necessary documents are easily accessible online.

From the beginning, one of the Air Bank's main goals has been to build a stable base of loyal clients. The management of Air Bank has been successful in achieving this goal, and has even surpassed expectations. The Chairman of the Board, Michal Strcula, claimed in the 2016 annual report (Air Bank, 2016) that for the first five years of business they had planned for half the yearly increase in clients, compared to actual yearly increase. Air Bank reported that in 2019 they managed to increase the number of clients from 673 thousand to 788 thousand clients (Air Bank, 2019).

The issue of bank runs is always more prominent during crises than during economic booms. According to the IMF global economic outlook, (IMF, 2020) the Covid-19 pandemic will have a much bigger impact on the global economy than the financial crisis of 2007 and 2008. In order to protect lives, widespread closures of economies and lockdowns were used to slow the spread of the virus. Therefore, the health crisis has had a critical impact on global economic activity.

Workplace closures were disrupting supply chains, and with that came lower productivity. Fear of contagion, lay-offs, and declines in income slowly increased the uncertainty about future economic development, forcing people to spend less, which then triggered further business closures and job losses. This shutdown of a significant portion of the economy will take its toll on global economic growth. The IMF expects (IMF, 2020) a sharp contraction of 3 % on global economic growth in 2020. The Czech Republic should, according to this IMF report, expect a contraction of 6,5 %. With the contraction of economic growth, business closures, and declines in income, unemployment rates can rise, thus increasing the risk of widespread defaults. From economic history we know that in a times of economic distress, the probability of bank runs increases.

The Czech National Bank has proposed a recommendation (CNB, 2020) for Czech banks to pause their dividend payments in order to prevent capital vulnerability. Also in the spring 2020, the Czech National Bank increased the weekly number of monetary operations in order to provide liquidity to banks. This means that banks have more possibilities to increase their liquid position. Instead of one weekly monetary repo operation, there are three possible week-days to buy liquidity for fixed repo rate without any markup.

Even though there have been no sudden bank runs within the first few months of Covid-19 pandemic, according to The Wall Street Journal (Ackerman, 2020) a few branches of U.S. banks and credit unions near New York and Seattle were reporting depositors making large withdrawals, sometimes reaching more than 100,000 U.S. dollars. These withdrawals appeared to be motivated by recent financial-market confusion over the coronavirus pandemic.

While the bank run literature is quite wide, the papers closest to ours are the ones based on Ziegler (2004) model of bank run. Petey and Soula (2018) use Ziegler (2004) model to measure a bank exposure to liquidity risk. They apply the model to a sample of European banks from 2004 to 2014. They find that banks outside of Eurozone seem to be more affected on average by stressed liquidity conditions, than banks within Eurozone. Petey and Soula claim that their result might reflect the ability of European Central Bank to better manage the effects of systemic events on the money markets.

Zhang (2016) uses model proposed by Ziegler and analyses the game of bank runs using stochastic volatility model, which assumes that asset value volatility is driven by mean-

reversion Ornstein-Uhlenbeck process. He later uses formula for equity value triggering bank run and analyses initial funding and recapitalization decision.

Zhang et al. (2020) combine option pricing and game theory to obtain formula for the value of bank equity with bank run risk. Unlike Ziegler (2014), Zhang et al. focus on liquidity ratios, which are derived from the perspective of bank's shareholders. On Chinese listed banks Zhang et al. show the gap between the optimal liquidity ratios and current ones and explain time-series and cross-sectional changes in liquidity and credit risk of banks.

The game theory analysis of options approach to the problem of bank run which we analyse in this paper is similar to an approach to analysis of endogenous bankruptcy which we used in Janda and Rojcek (2014). In that paper we modelled the financial distress of Wall Street investment bank Bear Stearns and Co. Inc during financial crisis of 2008.

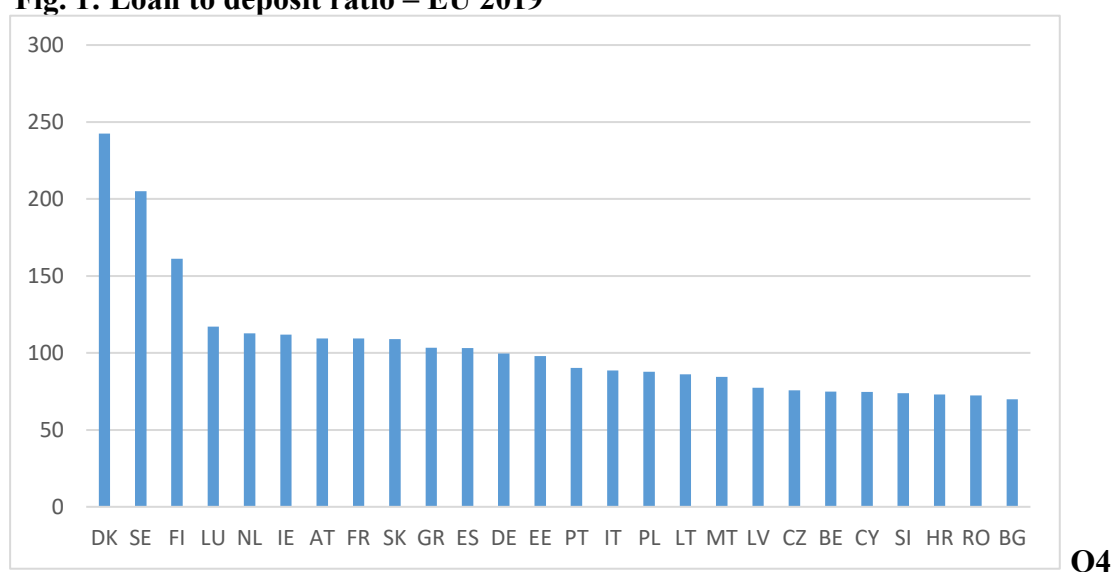
In the context of Czech banking sector, the only other empirical academic papers explicitly dealing with modelling bank run on Czech data which we discovered by a simple Google Scholar search were papers by Klepková Vodová (2015) and by Klepková Vodová and Stavárek (2017). While our basic modelling approach is different from Klepková Vodová (2015) and Klepková Vodová and Stavárek (2017), we also take care to incorporate some of their insights and modelling approaches in our paper and in that way firmly embed our paper into accumulated body of knowledge in the relevant Czech literature.

2. Factors affecting the susceptibility of Czech banks to a bank run

The Czech banking system is characterized by relatively high liquidity. Figure 1 shows that the Czech ratio of loans to deposits is one of the lowest in the European Union. The rest of Czech bank assets are held in the form of short-term interbank deposits, government bonds, and deposits in the central bank. Therefore, the Czech National Bank absorbs liquidity rather than providing it (Klepková Vodová, 2015).

The study done by Klepková Vodová and Stavárek (2017) on factors affecting the susceptibility of commercial banks in the Visegrad group to a bank run shows that the susceptibility of Czech banks is primarily determined by two macroeconomic factors out of seven possible economic factors and two bank-specific factors out of seven bank specific factors considered in that study.

Fig. 1: Loan to deposit ratio – EU 2019



Source: ECB Statistical Data Warehouse; <http://sdw.ecb.europa.eu/reports.do?node=1000003329&fbclid=IwAR0-8Iz4MrhlOEXSWMQdf7xipj2C96jQzdN9rKvf-MaEV0PMXo9KUdXuu-Y>

According to Klepková Vodová and Stavárek (2017), the two most significant macroeconomic factors affecting the susceptibility of bank runs in the Czech Republic are unemployment rate and interest rates on loans. Unemployment rate can be regarded as an indicator for the overall health of an economy, therefore higher values of unemployment rate increase vulnerability of banks to a run. The second macroeconomic factor, interest rates on loans, is connected with bank's profitability. The higher the interest rate, the higher the bank's profitability from lending. Furthermore, with higher accumulated profits from lending, a bank is better prepared to withstand a crisis.

Without a doubt, it is certain that the coronavirus pandemic will cause an increase in the unemployment rate worldwide. In the first week of April more than 6,6 million of Americans lost their jobs, and with this trend, economists predict that the unemployment rate can reach 15%. (Rushe, 2020). In the Czech Republic the analysts predict that unemployment rate could increase to 10% from 3% before the coronavirus pandemic. This rapid increase in unemployment rate increases the susceptibility to and probability of a bank run.

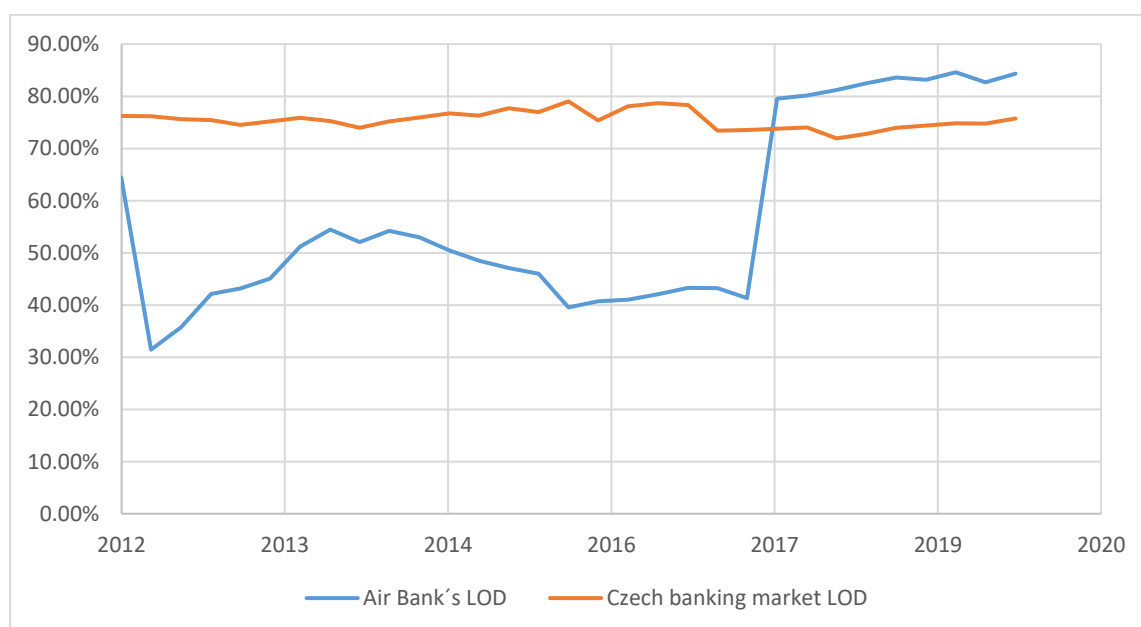
The Czech National Bank decreased the 2W repo rate two times in March 2020 (CNB, 2020). From 2.25 % in February to 1.75 % in the middle of March and again to 1 % at the end of March

(CNB, 2020). It is certain that the decrease in the 2W repo rate will affect the interest rate on newly provided loans, and therefore increase the susceptibility of banks to possible runs.

The two most significant bank specific factors affecting the susceptibility to bank runs are connected with bank's liquidity and profitability. As an indirect measure of a bank's liquidity, the share of loans to deposits is used. This ratio compares illiquid assets with liquid liabilities. Therefore, the lower the ratio, the more liquid the bank is and the more able to withstand the crisis. Return on assets is the factor most linked with profitability. Klepková Vodová and Stavárek (2017) suggest using this variable lagged by two years, which means that in the case of sudden withdrawals, safer banks are those which were financially stable in the past.

Figure 2 shows that for seven years before Covid-19 pandemic the ratio of share of loans in deposits (LOD) in Czech banks was stable around 75%. On the other hand, Air Bank's LOD value until end of 2016 was much lower than the Czech average, making the bank more liquid than the average Czech bank. Since 2017, Air Bank's LOD has exceeded the Czech average by almost 10%, which makes Air Bank more vulnerable to a possible bank run than the average Czech bank.

Fig. 2: LOD comparison

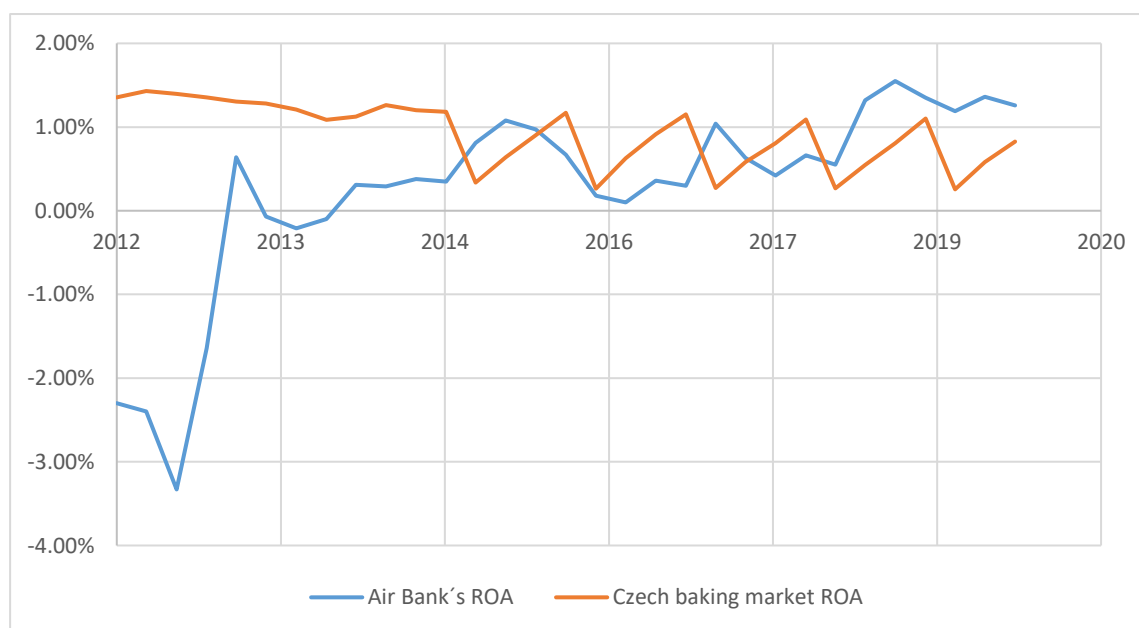


Source: Air Bank a.s., CNB

The second bank specific factor that affects the susceptibility of Czech banks to a possible bank run is return on assets. From Figure 3 it can be observed that since mid 2017 Air Bank's return on assets has been higher than average in the Czech banking sector. Having the return of asset variable lagged by two years shows that Air Bank should be less susceptible to a potential bank run.

In Air Bank's case, there is a delicate balance between profitability and liquidity. At the end of 2016, Air Bank lowered its high liquidity buffer and started providing more loans. This action worsened Air Bank's liquidity position, which resulted in an increase in the share of loans to deposits. On the other hand, with a time lag, it boosted Air Bank's profitability. However, it may be far more difficult for a bank with a worse liquidity position due to higher lending activity to withstand the impact of a crisis than for a bank with lesser lending activity and a larger buffer of liquid assets (Klepková Vodová, 2017).

Fig. 3: ROA comparison



Source: Air Bank a. s., ECB

3. Theoretical model

The determination of equity value triggering bank run used in this paper is based on a model introduced by Ziegler (2004). This model integrates a probability of a bank run with a bank equity valuation. Bank's equity is valued as a down-and-out call option, because down-and-out call option can disappear prior to its maturity, when the underlying's asset price reaches given point. In our case, when the conditions for a bank run are satisfied.

The model considers two representative depositors. Both depositors have initially deposited X_0 units of money into the bank. At the same time equity holders added for each monetary unit deposited by depositors additional $x > 0$ units of capital into bank. It is assumed that depositors have a right to withdraw their full amount of deposits from the bank without giving prior notice. Therefore, the bank additionally needs to take liquidation costs in the event of a run into account. The total asset value with liquidation costs equals (1), where S_t represents the value of bank's assets and α proportional liquidation costs in the event of a run.

$$2(x + 1)(1 - \alpha)S_t. \quad (1)$$

Pay-off function for depositor, who withdraws first (2) equals

$$\min[2(1 + x)(1 - \alpha)S_t, X(t)]. \quad (2)$$

Pay-off function for depositor, who withdraws second (3) equals

$$\max[0, 2(1 + x)(1 - \alpha)S_t - X(t)]. \quad (3)$$

The bank is exposed to a bank run as soon as both depositors decide to withdraw first. From pay-off functions, it can be derived that a bank run occurs as soon as the face value of deposits is higher than the total asset value net of liquidation costs (4).

$$X(t) > (1 + x)(1 - \alpha) S_t. \quad (4)$$

Having more than two depositors does not conceptually affect the marginal conditions for a run, therefore, the model can be applied to real life cases, where banks have thousands of depositors.

When deriving the formula for equity value triggering bank run we make three additional assumptions:

- As soon as the face value of deposits is higher than the total asset value net of liquidation, $X(t) > (1 + x)(1 - \alpha) S_t$, a run immediately takes place.
- A bank run happens very swiftly and equity holders aren't able to provide new capital in order to prevent or stop a bank run.
- Bank can liquidate its project even if bank run isn't happening, but at a proportional variable cost of β , where $\beta < \alpha$.

The bank holds a perpetual down-and-out call option on asset value net of liquidation, with a time-varying strike price of deposits $X(t)$ and a knockout price $K(t)$ (5), which is dependent on each depositor's run decision.

$$K(t) = \frac{(1-\beta)}{(1-\alpha)} X(t). \quad (5)$$

The value of perpetual down-and-out call option $C_\infty((1 + x)(1 - \beta)S_t, K(t))$ represents the value of the bank's equity when depositors are choosing to withdraw their deposits from the bank.

It may be shown that equity value triggering a bank run equals asset value net of liquidation minus the losses occurred when the expected when bank run happens (6). Losses are equal to discount, which results from the knock-back feature of the option.

$$C_\infty = (1 + x)(1 - \beta) \left(S_t - \left(\frac{X(t)}{(1+x)(1-\alpha)} \right)^{\gamma^*+1} S_t^{-\gamma^*} \right), \quad (6)$$

where γ^* equals to:

$$\gamma^* = 2 \frac{r-r^*}{\sigma^2}, \quad (7)$$

where r represents the risk-free interest rate, r^* represents interest rate paid on deposits and σ is a standard deviation of bank's asset value.

The down-and-out call option represents the possibility that a bank can face an illiquidity event a long time before the maturity of all bank's issued debts. The illiquidity event is connected with the value of bank's assets as it is shown in the equation above (6). Petey and Soula (2018)

mention that the framework proposed by Ziegler (2004) does not allow to differentiate between illiquidity and insolvency. However, the illiquidity can be a herald of insolvency.

4. Data construction

The equation for computing equity value which triggers a bank run has eight variables as its parameters:

1. bank's asset value S ,
2. face value of deposits $X(t)$,
3. risk-free interest rate r ,
4. interest rate paid on deposits r^* ,
5. σ as standard deviation of bank's asset value S ,
6. capital provided by equity holder at initial time x ,
7. α as proportional liquidation costs in the event of a run,
8. β as proportional liquidation costs if no run occurs.

A bank's asset value S may be easily obtained directly from a company's balance sheet for Q3 of 2019. Thus, Air Bank's asset value was 115,815 million Czech Crowns in 2019.

As in the case of asset value, the face value of deposits $X(t)$ can also be directly obtained from a company's balance sheet. The face value of money deposited in the bank equals to 104,862 million Czech Crowns.

In this model, we will use a yield on a Czech 10-year government bond as a proxy for a risk-free interest rate r . In April 2020, the yield on 10-year Czech government bond was 1.39% p.a.

To determine the interest rate paid on a deposit r^* , we will use deposit structure from Air Bank balance sheet data in Table 2.

Tab. 2: Client's deposits in Q3 2019

	Deposits (mil. CZK)	Interest Rate
Current accounts	23 382	1,00 %
Savings accounts	76 480	1,50 %

Total	104 862	
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Source: <https://www.airbank.cz/file-download/informace-o-air-bank-k-30-9-2019-cast-1.xlsx>

With data from Table 2 we compound proportional interest rate, which yields 1.36% p.a. The standard deviation σ of asset value S is calculated over quarterly published asset value from Air Bank's foundation in 2011 until the present day, and rebased into percentage equivalent. In this way we obtain the standard deviation of 41.75 %.

Using interest rate differential $r - r^*$ and standard deviation σ , variable γ^* defined in (7) can be computed as.

$$\gamma^* = 2 \frac{1.39\% - 1.36\%}{0.4175^2}.$$

Variable γ^* equals to 0.0029 and it's used in later calculations.

In order to compute parameter x , initial capital and initial deposits must be known. Air Bank entered the market on 22nd of November, 2011. From their 2011 balance sheet, we find that initial capital was 500 million Czech Crowns and deposits totalled 2,223 million Czech Crowns. With these two values parameter x equals to 22.39%.

One of the parameters most difficult to determine, when using only publicly know data, is the proportional cost in the event of a run α . According to (4) run will occur as soon as the face value of deposits is higher than the asset value net of liquidation.

Expressing α from (4) yields

$$\alpha > 1 - \frac{X(t)}{S(1+x)}. \quad (8)$$

Using equation (8) above yields that setting α higher than 26% would result in a situation, where the asset value net of liquidation is lower than the face value of deposits and thus triggering a bank run. At the initial time shareholders provide capital which covers potential liquidity losses (9). Thus,

$$(1+x)(1-\alpha) = 1, \quad (9)$$

$$\alpha = \frac{x}{x+1}. \quad (10)$$

According to (10) in 2011 proportional liquidity costs in the event of a run (α) must had been equal to 18.29%. Since 2011 Air Bank lowered its liquidity buffer and started providing more

loans. The lower liquidity buffer leads to the higher liquidation costs in the event of a run. From these two conditions, we see that parameter α should not be outside interval from 18.29% to 26%. Therefore for further analysis we will consider parameter values of α inside this interval (18.29%, 26%) . We are going to use four values of parameter α each for every one fifth within this interval.

Tab. 3: α parameter values

α_1	19.839 %
α_2	21.385 %
α_3	22.930 %
α_4	24.476 %

Source: Authors' calculation

Last parameter to be determined is β , which stands for liquidity costs in a situation in which no run occurs. To determine parameter β we will use equation (11)

$$x = \frac{\left(\gamma^* \frac{1-\beta}{\beta}\right)^{\frac{1}{\gamma^*+1}}}{1-\alpha} - 1. \quad (11)$$

Solving for β yields

$$\beta = \frac{\gamma^*}{\gamma^* + ((1+x)(1-\alpha))^{\gamma^*+1}}. \quad (12)$$

Computing the value of β for each parameter α from Table 3 we get:

Tab. 4: β parameter values

β_1	0.295 %
β_2	0.301 %
β_3	0.307 %
β_4	0.314 %

Source: Authors' calculation

5. Computation of equity value triggering bank run

Now we take the parameters computed in the previous part, insert them into the formula (6) and compute equity value which causes depositors to run on a bank. Evaluating (6) for each pair of α_i and β_i yields the results in Table 5:

Tab. 5: Scenario cases of equitiy value triggering bank run (in mil Czech Crowns)

C_{∞_1}	10 924.10
C_{∞_2}	8 348.49
C_{∞_3}	5 630.39
C_{∞_4}	2 894.66

Source: Authors' calculation

C_{∞_i} gives us the equity value, which would trigger Air Bank's depositors to run on the bank. In our four scenario cases, the equity value triggering a bank run ranges from 2,894.66 million Czech Crowns to 10,924.10 million Czech Crowns. As defined earlier, the equity value triggering a bank run equals the asset value net of liquidation costs minus the expected losses resulting from a bank run. Therefore, the higher the proportional liquidation costs in the event of a run α_i , the lower the equity value C_{∞_i} triggering a bank run and vice versa.

The current value of Air Bank's equity is 8803 million Czech Crowns. Therefore, it is obvious that the first solution of equity value triggering bank run (C_{∞_1})=10924.1 mil Czech Crowns yields unrealistic scenario, because the run would have already occurred. Due to the fact, that we are using only publicly known data, proportional liquidity costs in the event of a run (α) must be estimated. The equation (10) sets the value for the liquidity costs in event of a bank run (α) during the foundation of Air Bank in 2011. Thus, using the liquidity costs in the case of a bank run (α_1), which is the closest to the level of α in 2011, provides an unrealistic scenario and can't be further used. Therefore we will consider higher values of liquidity costs in the event of a run (α) than Air Bank's foundation value in 2011.

The solutions C_{∞_2} , C_{∞_3} , and C_{∞_4} seem to be more realistic, because computed equity values triggering a bank run (C_{∞_i}) are lower than current equity value, but there are still great differences between the values. Therefore, we will examine three cases C_{∞_2} , C_{∞_3} and C_{∞_4} . Because, C_{∞_2} is the closest value to current value of equity, we will speak of this version as pessimistic. C_{∞_3} will be an optimistic version and the last one will be the very optimistic

version, because Air Bank would have to encounter a significant loss and almost two thirds of bank equity would have to disappear.

Pessimistic version

The pessimistic version yields that equity value triggering a bank run is $C_{\infty_2} = 8348.49$ million Czech Crowns, which indicates that Air Bank's current equity value needs to drop by 454.51 million Czech Crowns in order to trigger a bank run. This sudden drop in equity value could be caused by, for example, a marginal unexpected loss.

The pessimistic version of equity value triggering a bank run is the closest to the current value of banks' equity. If the real values of liquidation costs are equal or close to values of α_2 and β_2 Air Bank should pay attention to their business model and focus on decreasing the level of risky assets on their balance sheet, such as loans, and increase the value of safe assets, such as government bonds. In doing so, Air Bank would decrease the risk of a bank run, but on the other hand, it would sacrifice its profitability. This measure may be more suitable in the crises triggered by 2020 coronavirus, when economists predict an economic crisis, which could equal The Great Depression.

Optimistic version

The optimistic version yields that equity value triggering a bank run is $C_{\infty_3} = 5630.39$ million Czech Crowns, which means that Air Bank would have to incur a loss of 3172.61 million Czech Crowns. This loss can be caused by the default of more than 3.5% of loans provided to retail customers. This volume of defaults is slightly higher than the percentage volume of defaults during the years of 2008 and 2009, which was around 3.2% (Singer, 2009). Thus, similar losses to the ones experienced during the Global Financial Crisis would almost trigger bank run.

This version seems more realistic than the previous pessimistic version. Taking deposit insurance into consideration, when all of the deposits are insured, a marginal unexpected loss, which would wipe nearly a half of bank's equity, would definitely cause a panic among depositors. A group of depositors, who do not take into consideration deposit insurance, could cause a panic bank run. In that situation, it would be up to Air Bank and other banks to calm the panicking depositors.

Very optimistic version

The very optimistic version yields that equity value triggering a bank run is $C_{\infty_4} = 2894.66$ million Czech Crowns, which indicates that Air Bank's current equity value needs to drop by 5818.34 million Czech Crowns from the current 8803 million Czech Crowns. This loss would raise questions about Air Bank's financial health.

In the four presented versions of equity value triggering a bank run it can be shown how liquidation costs α_i and β_i affect the final value equity triggering a bank run. Due to the unknown value of fire sales costs, until the crisis begins, banks can only predict the expected costs.

6. Simulating bank run

In this section we will determine the susceptibility of Air Bank a. s. to a hypothetical run. Some central banks or other supervisory authorities have developed their own liquidity stress tests in order to simulate a possible bank run. For example, in the Netherlands, a model proposed by Van den End (2008), in Romania, a model suggested by Negri (2010), and in Czech Republic, a model developed by Komárková et al. (2011). The disadvantage of these tests is that they can't be performed with publicly known information.

Therefore, we are going to use a less complex liquidity stress test in order to simulate a bank run. This model is proposed by Klepková Vodová (2015), and it is similar to a model used by the Austrian supervisory authority (Boss, 2007) or Slovakian (Jurča and Rychtárik, 2006) supervisory authority. This model uses the following liquidity ratios:

Share of liquid assets in total assets

$$LIA_B = \frac{A_{LI}}{S_T} * 100(\%). \quad (13)$$

Share of loans in total assets

$$LOA_B = \frac{A_{Lo}}{S_T} * 100(\%). \quad (14)$$

Share of loans in deposits

$$LOD_B = \frac{A_{Lo}}{X(t)} * 100(\%). \quad (15)$$

The above mentioned studies (Boss et al., 2007; Jurča and Rychtárik, 2006; Negrilla, 2010; Rychtárik, 2009) simulate the deposit withdrawal rate around 20%. Therefore, in this model we will simulate a bank run which results in the withdrawal of 20% of client deposits. This decrease is applied on total deposits within Air Bank, while not taking agreed maturities of different types of deposits into account. In order to compute the stressed values of ratios, we need to subtract 20% of client deposits and accordingly 20% of liquid assets, because the liquid assets are used to repay withdrawn deposits. The following equations show stressed modifications of previously mentioned liquidity ratios.

$$LIA_S = \frac{A_{LI} - 0.2 * X(t)}{S_T - 0.2 * X(t)} * 100(\%). \quad (16)$$

$$LOA_S = \frac{A_{Lo}}{S_T - 0.2 * X(t)} * 100(\%). \quad (17)$$

$$LOD_S = \frac{A_{Lo}}{0.8 * X(t)} * 100(\%). \quad (18)$$

Now we conduct a hypothetical bank run simulating an outflow of 20% of client deposits. We use values from the Optimistic scenario accompanied by balance sheet data from the third quarter of 2019. We assume that the decrease in equity value, which triggered a bank run, was primarily caused by defaults on loans, therefore the decrease in the bank's equity value is caused by an equal decrease in illiquid assets. Also, we are going to calculate the highest value of deposits that can be withdrawn from Air Bank, that are still covered by liquid assets. All the liquidity ratios and their stressed values can be found in Table 6:

Tab. 6: Liquidity ratios

Share of liquid assets in total assets	
LIA_B	20.69 %
LIA_S	3.15 %
Share of loans in total assets	
LOA_B	76.33 %
LOA_S	93.21%
Share of loans in deposits	
LOD_B	84.31 %
LOD_S	105.39 %

Source: Authors' calculation

Base value of share of liquid assets in total assets (13) equals to 20.69 %, therefore, for this ratio, it is valid that the higher the value, the better the liquidity position of a bank. According

to the Czech National Bank financial report (ČNB, 2019) the average value of LIA in 2018 in the Czech Banking market was 41.2 %. The stressed ratio of liquid assets in total assets (16) is 3.15%, which indicates that despite the substantial decline in liquidity, Air Bank would be able to cover a 20% withdrawal of deposits.

Base value of share of loans in total assets (14) is 76.33 %. Higher ratio value indicates that bank focuses primarily on lending activity. Banks with lower ratio focus on interbank transactions or trading with securities. Stressed value of share of loans in total assets (17) is 93.21% which indicates that after 20% outflow of deposits Air Bank would still be able to cover already provided loans. As mentioned above, Air Bank's business lies in lending activity. Providing more loans is possibly more profitable for Air Bank, but the result of this scenario indicates that it is very important to accordingly balance the relationship between profitability and liquidity.

The share of loans to deposits (15) is an important ratio, which shows how many loans provided to retail customers are financed by client deposits. The base value of Air Bank's LOD has an average value of 84.31%. The stressed value of Air Bank's LOD (18) is 105.39%. The stressed value exceeds 100%, which means that Air Bank would need additional sources of funding, such as an interbank loan or an issuance of debt securities. Air Bank should focus on lowering this ratio, because client deposits are considered to be a more stable source of funding.

Our goal is also to find the maximum volume of client deposits which can be instantly withdrawn from Air Bank. This means finding the worst case scenario of client withdrawals which would dry out Air Bank's liquid assets. Using equation for stressed ratio of liquid assets in total assets (16) and solving for deposit withdrawals yields 22.85%. This indicates that if depositors withdraw more than 22.85 % of their deposits, Air Bank would be forced to fire sell its illiquid assets.

7. Conclusion

The aim of this paper was to estimate the danger of a bank run using a case study of a representative Czech retail bank. In order to estimate the value of equity which would cause a bank run, we have applied an approach consisting of a combination of option pricing and game theory proposed by Ziegler (2004).

The susceptibility of Czech commercial banks to a potential bank run should increase as the unemployment rate rises from its minimum values with the upcoming crisis. An additional factor that increases susceptibility to a bank run is the lowering of interest rates on loans provided to customers. Due to the specific factors affecting Air Bank, their susceptibility to a run is unclear. Air Bank's higher ratio of loans to deposits than the Czech banking market average makes the bank more susceptible to a run. On the other hand, in previous years Air Bank managed to have a higher return on assets than average in the Czech banking market, which indicates good financial stability.

Our estimation of equity value that would trigger depositors to run on Air Bank a. s. yielded three plausible scenarios. From these analyzed versions, it is clear that the equity value triggering a bank run is highly dependent on the variable liquidity costs in the event of a run. The versions were arranged from the most pessimistic to the most optimistic. The pessimistic scenario yielded that depositors would run on a bank as soon as the equity value decreased by 454,51 million Czech Crowns, which accounts for 5% of Air Bank's current equity value. The optimistic scenario yielded that the decrease of equity which would trigger a bank run is equal to 3 172,61 million Czech Crowns. This amount of loss represents 36% of the bank's current equity value. The last version is very optimistic, and yields that a decrease in equity of 5 818,34 million Czech Crowns causes a bank run, which is equal to 66% of Air Bank's a. s. current equity value.

The three proposed scenarios mentioned in the previous paragraph enable Air Bank a. s. to think about their customers' behavior in uncommon situations, resulting from significant losses. The most likely scenario which causes a bank run is the optimistic one. The reason is that reported loss of more than 3 billion Czech Crowns inter-annually will not go unnoticed, neither in times of growth nor in times of depression. Year-to-year losses of 5% of a bank's equity value is definitely alarming in a time of growth, however, during economic distress, minor losses are expected. A loss exceeding 5.5 billion Czech Crowns, which does not cause depositors to run on a bank, is only acceptable with very phlegmatic clients or clients acquainted with issues in the banking market.

The methodology proposed by Ziegler (2004), on which this paper is based, is built for retail banks with a simple balance sheet structure where liabilities consist of only deposits. Another weakness of this model is liquidity costs. If we are using only publicly known data, they need

to be estimated. Using publicly known data leads into multiple scenarios, as it is shown in this paper. Nevertheless, Ziegler (2004) introduced a very interesting methodology, which tries to predict behavior of depositors when a bank's equity is decreasing due to unexpected loss. Definitely, there is a need for more surveys and case studies to be undertaken. In these studies, it would be appropriate to use non-public bank specific data to estimate exactly the behavior of the model and precisely calculate all the variables used in it.

We also conducted a liquidity stress test, which is similar to stress tests used by supervisory authorities in some European countries. Our results show that Air Bank a. s. has enough liquid assets to withstand a significant outflow of deposits. However, after a simulated bank run, the ratio of loans to deposits (LOD) would exceed 100%. That means that even though the examined bank would survive a bank run, additional sources of financing would be necessary.

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