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Interaction between liquidity risk and bank solvency, a crucial effect in a framework of simultaneous equations

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Abstract: *The "2008-09" global financial crisis has underlined that the interaction between liquidity risk and bank solvency forms an important factor that makes banks particularly vulnerable to a global crisis. At the same time, stress-testing models do not consider the dynamics between solvency and liquidity risk the possibility of reducing the impact of stress on bank solvency and financial stability. In this context, the aim of this paper is to examine this highly relevant issue in the financial literature, and answer to the main question: Is the interaction between solvency and liquidity risk empirically significant in the context of the Algerian banks? Based on an econometric model using a simultaneous equation approach on panel data of 19 banks over 6 years running from (2016 to 2021). Our results validate our hypothesis about the interaction and show that these two risks are determined simultaneously. Building on this finding, we suggest that the authorities should emphasise developing integrated liquidity and solvency stress tests. Our results also show the need of the Algerian banks to set up a regulatory framework for liquidity in line with the international prudential regulations to enhance the performance of this sector.*

Keywords: *liquidity risk, banking solvency, simultaneous equation model, Algerian banks, Prudential regulation*

JEL Classification: JEL *C36, G12, G19, G21.*

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Introduction. With the rising prominence of subprime crisis assessment to reveal the main causes, one of the assumptions has revealed to be inadequate following this crisis, and which was the origin of the incapacity and the inability of the prudential rules, designed by the Basel Committee since the late 1980s in order to guarantee financial and banking stability in dealing with this crisis; was the fact that these current regulations and rules have underestimated and reduced the liquidity risk (Krykliy & Luchko, 2018). At that time, the regulator believed that the solvency capitalization ratio was more than enough and sufficient as a pivot for banking regulation and believed that these two risks (solvency and liquidity) were completely independent.

Therefore, the consequences of this crisis have strongly invalidated the presumption that bank solvency and liquidity are two distinct measurements by illustrating the high degree of porosity between illiquidity and insolvency in contemporary financial systems (SCIALOM, 2013). The main cause of bank insolvency did not come only from the asset side (deterioration in the quality of bank assets), but also from the liability side (funding). In spite of the deposit insurance mechanism, which is supposed to play a preventive role against the risk of bank runs, but is not enough to preserve bank liquidity, because liquidity can also come from different sources such as: funding liquidity produced by liabilities and market liquidity produced by assets[1].

Thus, the market tightening liquidity and the decline in the value of the associated assets, generate losses and banks failures, which leads to create a contraction in their capitalisation base (solvency problems). Under such situation, where the market has doubts about the solvency of their counterparties, lenders tray to ration out their financing and thus create liquidity problems for the banks. Consequently, the interactions between market illiquidity (of balance sheet assets) and that of financing (balance sheet liability) are well identified. The combination of these two factors can lead to spiralling illiquidity for banks.

In this context, the interaction between bank solvency and liquidity risks in the financial system is, therefore, an important factor leads to the financial crises severity (BCBS, 2015). Highly solvent financial institutions may be forced to liquidate assets, face losses, become insolvent and go bankrupt if they encounter a serious liquidity problem. Similarly, a financing liquidity risk is generated by the banks' solvency risks, resulting from the potential sale of assets. Besides, uncertainty over a bank's asset quality raises concerns about solvency risk. Hence, lenders may discontinue renewing their financing or request high costs.

Against this preceding background, the aims of this paper are as follows:

➢ **Firstly,** we explore the past research findings about testing the joint endogenous determination of solvency and liquidity risk.

➢ **Secondly,** we investigate how much of test the joint endogenous determination of solvency and liquidity risk in algerian banks. In this regards, this study attempts to answer the following main question:

Do bank solvency and liquidity risks influence each other simultaneously in the context of Algerian banks?

➢ **Finally,** we discuss the most adequat regulatory framework for the Algerian banks in line with international prudential regulations for liquidity.

For this purpose, this study performs to extend the existing literature by constructing a sample dataset include of 19 Algerian banks (including six public banks and 13 private banks), covering a 6-year period (2016 to 2021). This analyse is based on a a simultaneous equation model approach to test the joint endogenous determination of solvency and liquidity risk. This is motivated by our concern about the endogeneity of the dependent variables, as an equation-by-equation regression is likely to produce biased coefficients.

To conduct this study, the organization of this paper is as follows: Section 2 reviews the previous studies conducted on literature review about Liquidity-Solvency Interaction and formulates the hypotheses. Section 3 describes the variables, data, and model specification while Section 4 presents the empirical estimation and analysis of results. Finally, the last section concludes.

1. Liquidity-Solvency Interaction: Literature review and hypothesis formulation.

The “2008-09” global financial crisis has revealed that liquidity risks (financing and market) are intrinsically linked to indebtedness, credit risks and market prices changes . It is therefore crucial to treat the liquidity and solvency risks as interrelated and interdependent. Since that crisis, studies about this issue are

[1] Funding liquidity refers to the bank's ability to raise funds from the public to finance its activity, while market liquidity is defined as the ability of the asset or market to guarantee sales flows without a significant loss in value (Drehmann & Nikolaou, 2009).

increasing over time and several authors who have tried to validate these interactions in their theoretical and empirical models, using several methodologies.

In this context, this paper presents an overview of these initiatives trying to examine and highlight the importance of these interactions among solvency and liquidity risks, particularly in empirical terms, the variables used, their methodologies, the results they have produced and discuss suggestions that tackle this issue.

Authors who have investigated this issue include (Babihuga & Spaltro, 2014). They published a research paper about "Bank Funding Costs for International Banks" and based on an international panel to observe potential shocks to banks' funding costs spanning the period of 2001–2012 using a VECM model and endogenous variable includes "CDS spreads, Credit Default Swaps", an approximate measure of marginal funding costs, among the explanatory variables, the Tier 1 capital ratio". Findings pointed out that increasing capital buffers may potentially support bank lending to the real economy through reducing bank financing costs, they explain this result by the fact that a higher solvency risk limits a bank's access to financing. Consequently, a high capital adequacy ratio means controlled liquidity risk.

Another study was conducted by (Pierret, 2014) where similar observations have been also endorsed in his empirical study entitled "Systemic risk and the solvency-liquidity nexus of banks". An econometric modelling was carried out using a fixed-effects panel autoregressive vector regression (PVAR) model, for a sample of 49 US banks holding companies during the period 2000-2013. The model was based on two components of the balance sheet to measure liquidity risk (endogenous variable), namely: 1/Short-term debt (debt maturing in less than one year); And 2/Short-term liquid assets to measure the bank's ability to withstand liquidity risk. The difference between short-term debt and short-term liquid assets is subsequently used as an indicator of a bank's exposure to funding liquidity risk. Funding liquidity risk arises when a financial company cannot renew its short-term debt and/or finds it difficult to raise new short-term debt. As for solvency risk, the author also uses two measures: the expected capital shortfall (SRISK)[2] and the regulatory capital ratio (Tier 1) as an alternative measure. The main result of this study suggests, in the same vein as work in the literature explaining the risk of banking panics linked to solvency risk, that the bank loses its access to short-term financing when the market has doubts about its solvency, in the event of a crisis, and conversely, a high financing liquidity risk (more short-term debt) increases the solvency risk in the event of a crisis.

Simirarly, another study carried on by (Aymanns & al., 2016), they have also studied this issue using two proxies for bank funding costs (a) the average funding cost (the ratio of interest expense to total liabilities over the period under consideration) and (b) the interbank funding cost (the ratio of total interest expense on interbank borrowings to total funds raised from other banks). The measure of solvency is obtained by applying a principal components analysis (PCA) to a variety of measures of bank capital, including the Tier 1 ratio, the total regulatory capital ratio, and the leverage ratio. The main conclusions of the study are: (1) Estimation of the parameters of the linear panel using the generalised method of moments (GMM) shows that solvency is negatively and significantly related to bank financing costs (for both measures). (2) The magnitude of this effect is stronger for interbank financing costs than for average financing costs. (3) In times of stress, the cost of interbank financing is more sensitive to solvency than in normal times. Finally, the authors conclude that (4) the relationship between the cost of financing and solvency appears to be non-linear, with a greater sensitivity of the cost of financing to lower levels of solvency.

In addition, (Distinguin & al, 2013) pursued a different methodology from previous studies to analyse the relationship between a bank's solvency and its liquidity. Thus, rather than focusing on funding costs, the authors studied the interaction between solvency and funding volumes. Their analysis is based on a sample of 870 listed US and European commercial banks from the period 2000 to 2006. To measure solvency, the authors use regulatory capital ratios as the dependent variable (T1 and T2). For liquidity, they use two different measures as dependent variables: the inverse of the net stable funding ratio (NSFR) and another

[2] (Acharya & al, 2012) define this measure as the difference between the regulatory capital ratio applied to the expected value of assets in the event of a financial crisis and the expected market value of capital. The stress scenario is defined as a market event characterised by a 40% fall in the market's equity index.

indicator called liquidity creation (LC), which is obtained by a weighted sum of liquid and illiquid assets and liabilities in terms of total assets. The econometric model used in this study is specified by a system of simultaneous equations (four equations). In the solvency equation, exogenous variables such as return on equity (ROE), loan loss ratio (LLP), log of total assets (bank size) and dividend payout ratio are determinants of solvency. In the liquidity equation, ratios measuring, respectively, market power (the ratio of the bank's total assets to the total assets of the banking system), GDP growth, the central bank's policy rate and the spread between the one-month interbank rate and the central bank's policy rate are treated as exogenous variables. Their results suggest that banks with high liquidity transformations have low regulatory capital ratios (the LC coefficient is negatively and significantly correlated with the total regulatory capital ratio), and conversely, banks with low regulatory capital ratios have higher measures of liquidity transformation (the coefficient on the solvency ratio is negative in the liquidity equation for both measures).

Finally, another interesting study was carried out by (Schmitz & al, 2017) using data of 54 large banks, from six advanced countries over the period 2004-2013. To account for the endogeneity of banks' funding costs and solvency positions, the authors used, as in (Distinguin & al, 2013) a simultaneous equations approach to estimate the contemporaneous interaction between solvency and liquidity. The results suggest a non-linear relationship and show that the interactions between liquidity and solvency may be more important than suggested by the existing empirical literature. A 100-basis point increase in regulatory capital ratios is associated with a decrease in banks' funding costs of around 105 basis points. A 100-basis point increase in funding costs reduces regulatory capital buffers by 32 basis points.

Evidence from the literature suggests that: (i) the interaction between solvency and funding liquidity is indeed statistically significant, and (ii) it may be economically relevant, particularly during periods of stress. In this context, the inability to adequately model the interconnections and link between solvency risk and liquidity risk can lead to a dramatic underestimation of risk. One conclusion of this first part is that stress testing models that do not take into account the dynamics between solvency and funding costs are likely to underestimate the impact of stress on bank solvency and financial stability.

Drawing from the foregoing literature and past studies, we propose the following main hypothesis to further contribute to this field of research:

Main hypothesis: The liquidity of a bank and its solvency are determined jointly. Thus, the interaction between a bank's solvency and its liquidity is statistically and economically significant.

2. Research methodology

In this research, we pursue an empirical approach to meet our objective. An econometric study will be carried out to verify the empirical validity of our hypothesis of the link between solvency risk and liquidity risk.

A review of the literature on solvency-liquidity interactions revealed that beyond theoretical models (Liang et al., 2013; Kapadia et al., 2013; Morris & Shin, 2016), this issue has not been sufficiently addressed empirically, particularly in studies of developing economies where little research has been done on this issue (Pierret, 2015). To this end, we fill this gap in the literature and develop an empirical model to assess the effects of solvency-liquidity interactions on the behaviour of Algerian banks. These interactions can then be used to parametrize a joint liquidity and solvency stress test (as opposed to stand-alone liquidity stress testing exercises) that takes into account the interactions between the risks associated with these two important banking phenomena. This part will be of crucial importance for our banks in their prudential stress tests, especially as the latter is implemented in isolation (independently of each other). Finally, we show in this study that ignoring the effects of the link between solvency and liquidity can lead to the amplification of losses on equity capital due to a financing risk arising from liquidity needs[3].

To capture this interaction, the existing literature states that, in principle, empirical studies should focus on very-short period banking data (BCBS, 2015; Aymanns & al, 2016; Schmitz & al, 2017) so that the

[3] Our analysis predicts that neglecting the dynamic characteristics of the interaction between solvency risk and liquidity risk in the stress tests could lead to a significant underestimation of the impact of the stress on the bank's capital.

estimates are of better quality. In our context, this is an important gap in our analysis. Indeed, and due to the absence of these sensitive data, our empirical research will be conducted on slightly longer data. Thus, our data consists of an unbalanced panel of 19 banks (6 public banks and 13 private banks), covering a 6-year period (2016-2021). Our main source of data is the annual balance sheets of the banks concerned.

2.1. Summary and description of variables

Several measures are used in the literature when measuring the link between bank solvency and liquidity. In our study, we differ slightly from studies in the literature that focus mainly on the funding cost component as a proxy for liquidity risk (Babihuga & Spaltro, 2014; Aymanns & al, 2016; Schmitz & al, 2017). Within this framework, the approach we pursue focuses on the other component of risk, which is the quantity of funding on which the bank depends in the event of a liquidity shock. In fact, funding liquidity risk has two components: a price component corresponding to the random cost of obtaining liquidity from different sources and a quantity component corresponding to the amount of outgoing cash (disbursement) (AZZOUZI IDRISSI & MADIÈS, 2016).

Thus, for robustness reasons, two different proxies are used in our analysis to measure liquidity risk. Our first measure of liquidity is a narrow indicator of liquidity creation (LC) defined by (Berger & Bouwman, 2009) and (Distinguin & al, 2013) which measures the bank's ability to create liquidity from its liquid and illiquid liabilities. This indicator is a weighted average of liquid and illiquid assets and liabilities in terms of the total balance sheet. To calculate this indicator, we use the same definition applied by (Berger & Bouwman, 2009). In the first stage, all assets and liabilities are classified as liquid or illiquid, depending on their maturity and category. An asset is deemed to be liquid, by the Basel definition, if it can be easily liquidated (converted into cash), even in times of stress, without incurring a significant loss. A liquid liability is one with a high degree of payability, i.e., one that can be withdrawn more easily and at any time (in principle, short-term liabilities with a maturity of no more than one year are liquid liabilities). Each asset and liability is then given a weighting of 0.5.

$$LC^{4} = \frac{0.5*illiquid\ assets - 0.5*liquid\ assets + 0.5*liquid\ liabilities - 0.5*illiquid\ liabilities}{Total\ assets} \quad (1)$$

Our second proxy is a measure of liquidity transformation defined by (Deep & Schaefer, 2004). They define the liquidity transformation gap or "LTgap" as :

$$LTgap = \frac{liquid\ liabilities\ (passifs\ liquides) - liquid\ assets(actifs\ liquides)}{Total\ assets} \quad (2)$$

These two measures are used in this study as a proxy for a bank's exposure to funding liquidity risk. Funding liquidity risk arises when the bank is unable to honour its short-term commitments, in other words, when it cannot renew its existing short-term debt and/or raise new short-term debt. A bank with a high maturity mismatch is more exposed to funding liquidity risk. In the same vein, a high concentration on illiquid assets is considered a source of risk for the bank. The more liquidity the bank creates by granting illiquid loans, the more exposed it is to funding liquidity risk. This arises when the expected inflows from loan repayments, which are by nature scheduled, are out of sync with the potential outflows from depositors, which can occur at any time. Under stressful conditions, depositors may 'run' to the banks and withdraw their deposits, leading to massive withdrawals. In this case, liquidity creation increases the bank's exposure to risk, as its losses increase with the level of illiquid assets to satisfy unexpected liquidity demands (Distinguin & al, 2013).

The difference between short-term debt and liquid assets is called liquid asset shortfall (Pierret, 2015). A negative liquid asset shortfall represents the amount of liquid assets that would remain if the bank lost full access to short-term funding. Liquid liabilities consist of short-term deposits and other liabilities with a residual maturity of less than one year, while illiquid liabilities consist of other liabilities with a residual maturity of more than one year (Term deposits, other liabilities....). Liquid assets include cash in hand (dinars and foreign currencies), central bank reserves, Treasury deposits, Treasury bonds, non-financial corporate bonds, and covered bonds with the highest ratings.

[4] In the absence of a detailed breakdown of off-balance sheet commitments in our database of Algerian banks, we measure the liquidity created by banks or their exposure to liquidity risk solely based on balance sheet positions.

In the solvency equation, the regulatory capital ratio (overall solvency) is used as the dependent variable. In doing so, we build on the work of (Distinguin & al, 2013; Schmitz & al, 2017; De Bandt & al, 2020) who used this measure of bank capital to assess solvency risk and capture the feedback from bank solvency to liquidity risk. The total capital ratio is the ratio of total regulatory capital to risk-weighted assets:

$$K\_RWA = \frac{\text{fonds propres réglementaires}}{\textit{Actifs pondérés des risques}} \quad (3)$$

In addition to these dependent variables, other exogenous variables are used in our analysis as explanatory variables. In the solvency equation, the return on equity (ROE) as a measure of profitability, the loan loss provision (LLP) ratio as a proxy for credit risk, the GDP growth rate (GDP), and the logarithm of the total balance sheet (SIZE) as a proxy for the size of the bank are the exogenous variables. In the liquidity equation, the liquid assets ratio (LA), the loan-to-deposit ratio (LDR), and the off-balance sheet ratio (OBS) take account of off-balance sheet positions and the central bank's key rate (CB) as a proxy for monetary policy are also treated as exogenous[5] variables. Our selection of explanatory variables in the two liquidity and solvency equations largely follows the existing literature (Distinguin & al, 2013; Hasan & al, 2014; Schmitz & al, 2017; De Bandt & al, 2020).

Table 1. Summary of the literature review on the determinants of bank solvency and liquidity

Variables	Expected sign	Reference
Dependent variable: bank solvency		
ROE : Net profit/equity	+	(Berger & al, 2008; Distinguin & al, 2013)
LLP: Provisions for Loan Losses /Total Loans[6]	-	(Ayuso & al, 2004; Fonseca & González, 2010)
GDP: Annual percentage change in GDP	-	(Distinguin & al 2013; Vodová, 2019)
SIZE: Bank size approximated by log (total assets)	-	(Vodová, 2019; De Bandt & al, 2020)
Dependent variable: bank liquidity risk		
LA : liquid assets/total assets	-	(Gafrej & Abbes , 2017; Ghenimi & al, 2020)
LDR : total loans/total deposits	+	(Saeed, 2014; Christaria & Kurnia, 2016)
OBS: Total off-balance sheet commitments/ (total assets + total commitments)[7]	-	(Al-Harbi, 2017)
Monetary policy: central bank key rate [8]	-	(Rauch & al, 2010; Distinguin & al, 2013)

Source: Prepared by the author.

2.2 Model specification and choice of estimation method:

To answer the question: of whether solvency and liquidity risks are determined jointly, we use a simultaneous equations framework, consisting of two equations. Similar to (Schmitz & al, 2017; De Bandt & al, 2020), our approach allows for the endogeneity of dependent variables due to their dual status (the endogenous variable of one equation appears as an explanatory variable of another equation) [9]. The structural form of a system of simultaneous equations is as follows:

$$Y_{i,t,1} = \alpha_{i,1} + \beta_0 y_{i,t,2} + \sum_{j=1}^{m} \beta_j \boldsymbol{X_{i,t,j}} + \epsilon_{i,t,1} \quad (4)$$

$$Y_{i,t,2} = \alpha_{i,2} + \gamma_0 y_{i,t,1} + \sum_{j=1}^{n} \gamma_j \boldsymbol{Z_{i,t,j}} + \epsilon_{i,t,2} \quad (5)$$

[5] We wanted to include a dummy variable to reflect the effect of the COVID-19 health crisis during the period 2020-2021, as this variable could cause a multicollinearity problem and therefore distort our analysis, which is why we decided not to include it among our explanatory variables.

[6] It should be noted that the expected sign of the relationship between this variable (LLP) and the regulatory capital ratio is not clear in the literature. Given that bank capital can play the role of a safety cushion to absorb losses on risky and low-quality assets, banks incentivised to take higher risks could hold more capital (Berger & al, 2008). In addition, large credit losses can weaken bank capital as it is accumulated to cope with unexpected losses (Ayuso & al, 2004).

[7] According to (Schuetz, 2011), off-balance sheet (OBS) activities have a positive effect on bank liquidity. In his study, this author shows that banks with low liquidity tend to favour OBS activities because the bank sees them as a source of low-cost financing.

[8] The existing financial literature indicates the importance of monetary policy in explaining bank liquidity. According to (Berger & Bouwman, 2017), a monetary policy characterised by a relatively low policy rate, increases the supply of credit and consequently the creation of liquidity, which positively affects bank illiquidity and liquidity risk.

[9] When the error terms of the dependent variable are correlated with the independent (explanatory) variables, parameter estimation using conventional ordinary least squares methods gives biased results.

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Where i = 1,...,N denotes the individual banks, i = 1,...,T is the time index and ϵ represents the error term. Y i, t,1 and Y i, t,2 are the two endogenous variables (solvency and liquidity) and $X_{i,t,j}$ and $Z_{\_(i,t,j)}$ are the set of exogenous variables.

In simplified matrix form: $Y\Gamma = XB + U$

The dual status of the two endogenous variables creates an endogeneity problem that cannot be resolved by conventional ordinary least squares estimation methods. In this context, the estimation of simultaneous equation models first involves identifying the exogenous and predetermined variables and the endogenous variables. This stage is known as the identification phase (Bourbonnais, 2015). Next, the possibility of estimating the parameters is checked and the appropriate method is chosen.

The identification of a model with simultaneous equations refers to the possibility of estimating the parameters of the structural equations starting from the coefficients of the reduced form. Rewriting our simultaneous equations specification in reduced[10] form simplifies the problem and gives us :

$$Y = XB\Gamma^{-1} + U\Gamma^{-1} = XM + V, \text{ avec } M = B\Gamma^{-1} \text{ et } V = U\Gamma^{-1} \quad (6)$$

Statistically, several conditions must be met so that we can estimate the structural coefficients from the reduced-form coefficients and their respective standard deviations (extract the matrices B and Γ from an estimated M). This problem is known as the identification problem. If it is possible to deduce the structural parameters from the estimated parameters of the reduced form, we say in this case that the structural equation is identifiable[11]. In economic terms, identification can be addressed in the specification of the structural equation. If the same explanatory variables are used to identify two or more endogenous variables, then the model will be neither statistically identifiable nor economically significant.

Table 2. Identifiability order conditions

Identification rule	Conclusion
g – 1 > g – g' + k – k'	The equation is under-identified
g – 1 = g – g' + k – k'	The equation has just been identified
g – 1 < g – g' + k – k'	The equation is over-identified.

Source: (Bourbonnais, 2015).

Our model has two endogenous variables, Y1it and Y2it, i.e. g = 2, and K = 8 exogenous variables. In this case, the model is identified equation by equation. We can check the identification of each equation as follows:

- For the first solvency equation [E1], which has g' = 2 endogenous variables and K' = 4 exogenous variables, i.e.: g - g' + k - k' = 2 - 2 + 8 - 4 = 4 > g - 1 = 1, equation [E1] is over-identified.
- Idem for the second liquidity equation [E2], which has g' = 2 endogenous variables and K' = 4 exogenous variables, i.e.: g - g' + k - k' = 2 - 2 + 8 - 4 = 4 > g - 1 = 1, equation [E2] is over-identified.

Having checked the identification conditions for the two equations, we can conclude that our model is identifiable (over-identified model) [12]. We now need to choose the appropriate method for estimating the parameters of the simultaneous equation model. In our case, we can distinguish between two estimation methods: the Two-Stage Least Squares (2SLS) method and the Three-Stage Least Squares (3SLS) method. These two methods are the most widely used in practice. Both methods take into account the endogeneity of the dependent variables and are capable of estimating simultaneous equations.

The Double Least Squares (DLS) estimation procedure is based on the two-stage application of OLS. It involves first estimating the coefficients of the reduced form (regressing each of the endogenous variables

[10] Rewriting the system of structural equations in reduced form is achieved by expressing each endogenous variable in terms of the explanatory and predetermined (exogenous) variables only. This allows us to obtain equations that individually verify the hypotheses of an ordinary linear model and can therefore be estimated by the least squares method.
[11] Econometrically speaking, for a structural equation in a system of simultaneous equations to be identifiable, the number of a priori restrictions on this equation must be greater than or equal to the number of equations, minus 1.
[12] In other words, there are several ways of determining the structural parameters from the coefficients of the reduced form.

on all the exogenous variables). Then, in a second step, the endogenous variables are replaced in the structural equations by their values adjusted using the estimated models. The 3SLS method is adopted when the errors are autocorrelated and/or heteroskedastic and consists of combining the 2SLS with the GLS (Generalized Least Squares) estimator to take account of the correlation structure of the errors in each structural equation. Indeed, the biggest challenge in using these methods is identifying the right instrumental variables to overcome endogeneity and simultaneity biases. We address this challenge by performing several statistical tests to verify the validity and robustness of the instruments, as well as their exogeneities. The results of these tests are as follows (estimated by 2SLS):

Table 3. Specification tests for 2SLS estimation

Specification	**Specification 1**		**Specification 2**	
Endogenous regressors	K_RWA	LC	K_RWA	LTgap
Instrument quality (H0: instruments are weak): Stock-Yogo test/F-statistics				
F-*Statistic*	5.68436	38.1356	5.68436	32.6153
P-*Value*	0.0004	0.0000	0.0004	0.0000
Exogeneity of instruments (H_0: instrument is valid): Sargan's and Basmann's $\chi 2$ test				
Sargan -*Statistic*	20.0444	4.59438	23.8246	1.07029
P-*Value*	0.0002	0.2040	0.0000	0.7842
Basmann's-*Statistic*	22.4259	4.40767	27.7852	0.994469
P-*Value*	0.0001	0.2207	0.0000	0.8026
Durbin–Hausman–Wu test for endogeneity (H_0: specific variables are exogenous)				
Durbin statistic	2.07006	6.03519	2.31571	8.01355
P-*Value*	0.1502	0.0140	0.1281	0.0046
Wu-Hausman Statistic	1.97806	5.98075	2.21771	8.09091
P-*Value*	0.1625	0.0161	0.1394	0.0053

Source: Prepared by the author.

As the table above shows, most of the test results are satisfactory. First, we tested for each equation whether the instruments are weak and of good quality: the instrument quality test rejects the null of weak instruments in all equations [13].

Second, we performed the Sargan test for each equation to verify the exogeneity of the instruments. In the solvency equation, the results of this test indicate that the instruments are not entirely exogenous. However, these results are not very surprising and are in line with the financial literature, which advocates that the provisioning policy in the bank and the return on equity can be slightly endogenous to the solvency ratio (BCBS, 2015; Schmitz & al, 2017).

Finally, we tested the endogeneity of the dependent variables to clarify whether our solvency and liquidity variables are truly endogenous. The Durbin-Wu-Hausman test is significant for the liquidity equation and insignificant for the solvency equation. That suggests that endogeneity is less of an issue for the liquidity variable since the null hypothesis of the test is rejected with both liquidity measures.

To address the biases associated with weak instruments in the solvency equation, we opt for the LIML (limited information maximum likelihood) method instead of 2sls. That is one of the estimation methods that can be more powerful than 2SLS (Huang & al, 2021), and an alternative solution that has better properties than 2SLS with weak instruments (this estimator gives partially robust results and is less sensitive to instrument weakness than 2SLS estimates, especially for small sample sizes). In what follows, we present the results of estimation by the two methods LILM and 3SLS.

3. Empirical estimation and analysis of results

To capture the joint impact of bank solvency and liquidity risk, we estimate a system of simultaneous equations in panel data, as defined above. In the solvency equation, we regress the banks' regulatory capital ratio on a set of determinants from the previous literature and on a liquidity risk proxy. In the liquidity equation, we regress the liquidity risk proxy on a set of determinants described in the previous literature and

[13] However, the test statistic in the solvency equation is very low. According to (Stock & al, 2002) when the test statistic is less than 9.08 (for three instruments) we say that the instruments chosen are not robust. In other words, there is a weak correlation between the endogenous regressor (variable to be instrumented) and the instrumental variable(s).

on the solvency proxy. For reasons of robustness, we measure liquidity risk using two different indicators, as defined above: the liquidity creation indicator (LC) and another indicator known as the liquidity transformation indicator (LTgap). The table below summarises the results of the simultaneous panel estimation for the regulatory solvency measure K_RWA and the funding liquidity risk as measured by the two proxies (LC in specification 01 and LTgap in specification 02).

For each specification, the first column shows the results of the solvency equation based on the regulatory ratio, and the second column shows the results of the liquidity risk equation.

In specification 01, liquidity risk measured by the liquidity creation indicator (LC) is negatively and significantly correlated (at the 1% threshold) with bank solvency. This result is robust for the different estimation methods (3SLS) and for alternative measures of liquidity risk (specification 02). We explain this negative impact for both variants of the liquidity indicator on the solvency of Algerian banks by high liquidity creation increases the bank's exposure to credit risk and the provisioning rate of non-performing loans, which consequently decreases bank solvency[14]. In summary, the results show that our banks do not tighten their solvency standards when faced with higher illiquidity. They are not adjusting their capital ratio (K_RWA) and are in fact reducing their solvency when faced with higher illiquidity.

Furthermore, when studying reverse causality, we also show that the regulatory capital ratio has a significant negative impact (at the 10% threshold) on liquidity risk in both specifications[15]. This result means that higher regulatory capital requirements reduce liquidity creation, therefore, banks' exposure to liquidity risk, and conversely, banks with lower capital ratios have higher measures of liquidity creation[16].

Banks whose funding structure is centred on short-term debt (sight deposits) are exposed to refinancing risks due to insolvency and liquidity fears in the banking system. In addition, high liquidity creation increases the bank's exposure to liquidity risk, that arises when the bank is forced to sell these illiquid assets (usually at knock-down prices) to satisfy an immediate demand for liquidity from its creditors. This result is consistent with the findings of (Berger & Bouwman, 2009; Horvath & al, 2013; Distinguin & al, 2013) who also observed a negative and significant impact of capital on liquidity creation.

Our results are, therefore, consistent with the existing literature, predicting an inverse causality between liquidity risk and bank solvency (Horvath & al, 2013; Distinguin & al, 2013; Pierret, 2015; Aymanns & al, 2016; Schmitz & al, 2017) and validate fundamental hypothesis which states that liquidity and solvency risks are jointly determined. This result is, therefore, of crucial importance for our research. It shows the importance of studying the reverse causality between bank solvency and liquidity risk, whitch was previously ignored in the literature.

Regarding the analysis of the control variables, we observe that most of them are significant. In the solvency equation, the loan loss provisions (LLP) ratio has a negative and statistically significant coefficient in all specifications. Irrespective of a bank's provisioning policy, higher provisions reduce profits and hence regulatory capital. Our result is consistent with the findings of (Ayuso & al, 2004; Fonseca & González, 2010). However, this finding contradicts several research results (Berger & al, 2008; Boudriga & al, 2009). In the end, the financial literature does not give an exact picture of the nature of the relationship between provisions and the bank's regulatory capital, as this relationship is highly dependent on the bank's provisioning policy[17].

[14] High liquidity creation is generally linked to a high rate of non-performing loans (particularly in the case of public banks) and consequently to a high level of loan loss provisions, which reduces regulatory capital. Banks with a higher rate of non-performing loans, because they invest in riskier and less liquid assets, are more exposed to losses and are therefore less solvent.

[15] However, this negative and significant relationship is only observed when the simultaneous equation system is estimated using the LIML method, i.e. when the low quality of the instruments is taken into account in the solvency equation.

[16] This result argues in favour of the financial fragility hypothesis, according to which the increase in capital contributes to the deterioration of liquidity creation. According to (Diamond & Rajan, 2001) financial fragility favours liquidity creation because it allows banks to collect more deposits and grant more loans.

[17] For some banks, provisions are a means of absorbing any unexpected losses. For these banks, an increase in provisions reflects an increase in credit losses. Other banks, on the other hand, perceive provisions as a hedging instrument against credit risk. Thus, an increase in provisions reflects a prudent lending policy and generates fewer losses.

In contrast to our hypothesis, return on equity (ROE) has negative and significant correlation with bank solvency. That unexpected negative sign can be explained based on the bank's risk-taking behaviour. High profitability is linked to excessive risk-taking. Banks incited to take more risk to improve their profitability may suffer capital losses, which negatively impacts their solvency. Our result is consistent with the findings of (Büyükşalvarcı & Abdioğlu, 2011) and contradicts the results of (Berger & al, 2008; Distinguin & al, 2013).

Our last significant variable in the solvency equation is the size of the bank (SIZE) measured in our case by the logarithm of total assets. As we expected, this variable has a negative and significant sign (at the 1% threshold). This result means that the larger the size of the bank, the less solvent the bank. This result is consistent with the "too big to fail" doctrine, which states that large banks are less cautious about banking risks and have less incentive to build up capital buffers to absorb potential losses, because they rely on government intervention in the event of difficulties, given that their failure could cause a systemic crisis. Indeed, because of their "too big to fail" position, the large Algerian banks (particularly those in the public sector) may hold less capital beyond regulatory requirements. Our finding follows the results of (Vodová, 2019; De Bandt & al, 2020).

We found that liquidity risk is significantly explained by three determinants by focusing on the liquidity equation. In addition to the regulatory capital ratio, liquidity risk is affected by the liquid assets ratio (LA), the transformation ratio (LDR), and the off-balance sheet commitments ratio. About the first determinant, a negative and significant relationship is observed between the number of liquid assets and bank illiquidity. This result means that the greater the proportion of liquid assets held by the bank, the greater the bank's ability to deal with net cash outflows.

This result reflects the importance of fostering the resilience of a bank's liquidity risk profile by ensuring that it has sufficient high-quality liquid assets (cash and central bank reserves, financial securities with low-risk weights) to survive a stress scenario. Our result is consistent with the Basel III liquidity risk management guidelines, which require banks to hold, as part of their short-term liquidity ratio LCR, sufficient high-quality liquid assets (HQLA) to cover a potential net cash outflow (BCBS, 2013).

In the event of a shock, this may be particularly important for our public banks because of their heavy dependence on funding liquidity from the public sector. Sound management of liquidity risk therefore requires banks to avoid the stigma of being too dependent on liquid liabilities, and to hold sufficient liquidity cushions (made up of liquid assets) to be used in times of crisis or market volatility to mitigate liquidity risk. Accordingly, Algerian banks are strongly advised to maintain enough first-level liquid assets (coins and banknotes, eligible negotiable securities issued by governments, central bank reserves) of high quality that can be converted into cash inflows in times of stress without incurring undue losses.

The second determinant of liquidity risk is the transformation ratio, which is also a risk factor. This variable, which measures the risk of maturity transformation (transforming short-term liquid liabilities, such as sight deposits, into long-term illiquid assets) has a positive and highly significant sign (within 1% in both models) on liquidity creation (LC). Thus, the higher the maturity transformation risk, the higher the bank liquidity risk (insofar as any change in maturities may result in the bank failing to meet its obligations to its customers). This result is consistent with our hypothesis and with the literature review developed above (Saeed, 2014; Christaria & Kurnia, 2016) [18].

The last significant variable in the liquidity equation is the ratio of off-balance sheet commitments. This variable has a positive and significant sign (at the 1% threshold) in all specifications. This positive impact means, contrary to our hypothesis, that off-balance sheet activities favour the creation of liquidity in our banks and consequently liquidity risk. That is due to most off-balance sheet commitments (confirmed credit

[18] It should be noted that in some jurisdictions, compliance with a maximum transformation ratio threshold is a prudential obligation for banks. Thus, in order to ensure a better match between resources and uses and control the risk of maturity transformation, some central banks have introduced a transformation ratio as defined above, the threshold of which may not exceed a rate of 120% (we cite as an example the case of banks operating on the Tunisian financial market which are required in accordance with circular No. 18/10 of 01/11/ 2018 to keep this ratio at a ceiling level of 120%).

lines, bank guarantees granted) given by Algerian banks are subsequently materialised by a mobilisation of funds. In other words, off-balance sheet activity enables Algerian banks to increase their portfolio of illiquid assets by winning the loyalty of new customers. These commitments can be the source of liquidity risk for banks when they turn into unexpected balance sheet entries, exposing the bank to liquidity impasses (Cornett & al, 2011; Karim & al, 2013).

Moreover, our results indicate that monetary policy (TXD) is irrelevant in explaining bank liquidity. That means that the change in the policy rate has no significant effect on liquidity creation in the context of Algerian banks. In reality, this result is not surprising, given that the transmission of the Bank of Algeria's key rate to the banking system and the economy is weak. The low operational relevance of the key rate in the transmission of monetary policy has led the monetary authorities to use reserve requirements as their main instrument in the face of liquidity tensions, as observed during the recent liquidity crisis (IMF, 2021).

Table 4. Estimation results for the system of simultaneous equations between solvency and bank liquidity risk

	LIML estimate				**3SLS estimate**			
	Specification 01		***Specification 02***		***Specification 01***		***Specification 02***	
	K_RWA	*LC*	*K_RWA*	*LTgap*	*K_RWA*	*LC*	*K_RWA*	*LTgap*
K_RWA		-1.7641*		-2.5905*		-0.2576		-0.2845
LC	-0.1816***				-0.1941***			
LTgap			-0.2231***				-0.2398***	
ROE	-0.1638*		-0.1182		-0.3171***		-0.3060***	
LLP	-0.5220**		-0.5081*		-0.6105***		-0.6040***	
SIZE	-0.0285***		-.0293***		-0.0230***		-0.0228***	
GDP	-0.0231		-0.1148		0.1237		0.0700	
LA		0.1943		0.1313		-0.4077***		-0.6782***
LDR		0.3050***		0.1182		0.1624***		-0.0465
OBS		0.6474***		0.7530***		0.4497***		0.4339***
TXD		0.0953		-0.3268		2.7683		3.0751
Constant	0.8829***	0.1240	0.8797***	0.3658	0.8091***	0.07617	0.7902***	0.2383
Observations	113	113	113	113	113	113	113	113
R^2	0.2638		0.2627		0.2283	0.5051	0.2074	0.4499

This table presents the results of the estimation of system (1) using the two methods LILM and 3SLS for an unbalanced panel of 19 Algerian commercial banks over the period 2016-2021. The dependent variables are the regulatory capital K_RWA and the two measures of liquidity creation LC (specification 01) and LTgap (specification 02). The explanatory variables are : LLP (credit loss provisions) ROE (return on equity) SIZE (bank size) and GDP (growth rate) in the solvency equation. And: LA (quantity of liquid assets) LDR (transformation ratio) OBS (off-balance sheet liabilities) and TXD (policy rate) in the liquidity equation.* p<0.1; ** p<0.05; *** p<0.01.

Conclusion

According to the modern theory of financial intermediation, the bank's two main functions are maturity transformation and risk transformation. Risk transformation occurs when the bank accepts risk-free deposits and grants risky loans, maturity transformation results from the fact that the bank creates liquidity by transforming short-term debts (e.g. sight deposits) into long-term illiquid assets (Berger & Bouwman, 2009). The creation of liquidity is at the heart of banking activity and, therefore, at the origin of the stimulation of economic growth. However, recent experience has shown that liquidity creation (LC) is also a precursor of bank failures and financial crises (Berger & Bouwman, 2017). Consequently, excess illiquidity due to high LC is a primary source of banks' vulnerability to liquidity risk.

Using the two measures of liquidity creation defined by (Berger & Bouwman, 2009) and (Deep & Schaefer, 2004) as proxies for a bank's exposure to liquidity risk, and the regulatory capital ratio as a measure of solvency, we have attempted in this research to examine a highly relevant issue in the financial literature, namely the interaction between solvency and liquidity risk in the banking sector. Based on a range of previous studies indicating that capital and liquidity are likely to be jointly determined, we consider a simultaneous equation model to study the impact of bank liquidity measured from balance sheet positions on the regulatory capital buffer and a set of determinants considered in the existing literature. More specifically, we ask whether Algerian banks maintain or strengthen their solvency when faced with lower liquidity.

Our main results indicate that, unfortunately, our banks do not strengthen their solvency standards when they create more liquidity (i.e. when they finance a greater proportion of their illiquid assets with liquid liabilities). Although liquidity creation is the main activity for these banks, and their source of profitability, their appetite for credit risk could prevent them from assuming prudent management of liquidity risk. These results confirm the need to implement minimum liquidity ratios alongside capital ratios, as emphasised by the Basel Committee on Banking Regulation and Supervision. However, they also cast doubt on the effectiveness of the current liquidity framework. In particular, it focuses solely on transformation risk, which sometimes cannot be the sole source of vulnerability to our banks.

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