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Abstract

This paper analyzes the effect of Basel III adapted to WAEMU on the behavior of banks in the zone (intermediation and market activities). After having developed a model for optimizing the return on bank equity, under various constraints (balance sheet constraints, Basel III regulatory constraints), we resort to linear programming via the Danzig simplex algorithm and to a structure of reasonable rates to obtain the optimal values of the various bank balance sheet items. The results, obtained by comparing these theoretical values with the values observed before Basel III (before January 1, 2018), show an increase in the supply of loans, obtained not only from deposits and bank refinancing but also via resources from the financial markets. We can also observe the intuitive result of an increase of bank reserves in line with the constraint that Basel III imposes on banks to increase their liquidity. In short, Basel III tends to strengthen bank financing in the zone, while improving the soundness of banks through the constitution of larger reserves.

Keywords: prudential regulation, calibration, credit supply, linear programming.

Classification JEL : C44, E50, E58.

[1] West African Economic and Monerary Union. WAEMU countries are : Ivory Coast, Benin, Senegal, Burkina Faso, Togo, Mali, Niger, Guinee Bissau.

1. Introduction

In 2010, new prudential rules called Basel III came into force in developed countries. The aim was to overcome the limits of the Basel II rules, the complexity, procyclicality and inadequacy of which were revealed during the 2007-2008 financial crisis. The Basel III accords impose liquidity constraints and the holding of better quality capital on banks. The implementation of these rules started in 2018 in the WAEMU (West African Economic and Monerary Union) countries. One can wonder about the advisability of adopting within African economies with weak banking structures, a set of rules whose primary objective was to respond to the challenges that have arisen in countries with highly developed financial architectures. Studies that have attempted to assess Basel III in the WAEMU, make the common observation, beyond slight differences, that these reforms have a certain cost and can be counterproductive in terms of access to credit.

In particular, Finactu (2018) is advancing an additional cost of 700 billion FCFA, a sum difficult to mobilize by 2022, in a context of reinforcement of social capital still not completed. In fact, Basel III requires banks to gradually increase their capital, in order to respond appropriately to the new consideration of risks. This requirement for more capital, relatively easy for large groups and their subsidiaries, is not for all the 123 WAEMU banks. This requires more vigilance and more results to make this capital profitable. The new risk taking into account imposing even more capital, banks have two options: either they refuse to take additional risks and reduce their credits to the economy, up to their own funds, which reduces their income. Either they continue to lend to the economy but will have to raise more equity capital (counterpart resources).

A decline in the credit supply in thirty emerging countries under the effect of the Basel III agreements was highlighted by Figuet, Humblot and Lahet (2013). They show that these agreements induce, via liquidity ratios, a strong constraint on bank profitability which significantly affects balance sheet management, including the supply of loans which tends to decline. The negative effect of Basel III on the bank financing of the economy also emerges from the study by Levy-Garboua and Maarek (2014) applied to the euro area. More precisely, they show that the constraints of Basel III induce a substantial drop in the supply of credit, an increase in borrowing costs and a radical penalization of market activities. In the context of WAEMU, the central bank of the zone (BCEAO), aware of these perverse effects, has endeavored to adapt Basel III to its own realities. In doing so, it did not apply all of its provisions. She rejected standard approaches that would run counter to the financing objectives of the WAEMU zone.

In fact, the BCEAO strives for a balance between the resilience of the banking system and its ability to finance economies. According to Mbow (2018), the heart of Basel III reforms does not relate to equity but to qualitative aspects. The goal is that under this adapted version of Basel III, the WAEMU banks are better equipped to manage risks and benefit from the sound financial health of the banks, allowing them to finance economies. The data from the BCEAO seem to corroborate this assertion. In fact, customer loans increased from 61.9% in 2017 to 63.8% in 2018 after Basel III. Over the same period, investment securities fell from 25.3% of to 22.8%. More generally, at the balance sheet level, the annual growth in net uses fell from 19.6% in 2015 to 7.3% in 2018. One year after the implementation of Basel III, this rate increased with a annual increase of 9.8%. Bank resources, for their part, experienced a slight decline, from 11.5% in 2017 to 10.4% in 2018, after Basel III. It then increased in 2019, by 11.4%. The net banking income (NBI) in the WAEMU, which was up 10.8% in 2017 and 6% in 2018, only grew by 4.3% in 2019, one year after Basel III , the weakest increase recorded since 2015. As for the average solvency ratio of banks in the union, it went from 10.8% in 2018 to 11.6% in 2019 after Basel III.

What effects could the Basel 3 standards have on WAEMU banks, in terms of their credit activity and their market activities? Theoretically, we could expect that Basel III would force WAEMU banks to hold more liquidity and lead, by strengthening solvency ratios, to further reduce the credit supply in WAEMU than under Basel II. The relevance of Basel III with regard to the need to hold more liquidity could be called into question by the existence of excess banking liquidity in the WAEMU, due to uncertainties and the weakness of financial market returns. Furthermore, the need to strengthen solvency ratios in order to reduce the supply of credit to excessively risky projects does not seem necessary because this zone is characterized by strong economic and institutional uncertainties which de facto constrain the credit supply. This is one of the reasons that has always led UEMOA not to adopt the Basel II rules.

From these developments, it is difficult to perceive very clearly the effects of the implementation of Basel III on banking behavior. To what extent will the Basel III rules impact the behavior of WAEMU banks? Our objective is to rigorously assess (via a proven empirical analysis) the effects of Basel III on the intermediation and market activities of WAEMU banks. This article is structured as follows: after reviewing the theoretical and empirical literature on the effect of prudential rules in WAEMU (section 1), we develop the empirical methodology to address our problem (section 2). In section 3, we present, interpret and discuss the results obtained. Section 4 makes recommendations and concludes the article.

2. Literature review on the effectiveness of prudential rules

2.1. Description on Basel III requirements

The Basel III requirements have been introduced after the global financial crisis during which we have witnessed a build-up of excessive on- and off-balance sheet leverage in the banking system. In many cases, banks built up excessive leverage while apparently maintaining strong risk-based capital ratios. At the height of the crisis, financial markets forced the banking sector to reduce its leverage in a manner that amplified downward pressures on asset prices. This deleveraging process exacerbated the feedback loop between losses, falling bank capital and shrinking credit availability (BCBS, 2014). The Basel III framework introduced a simple, transparent, non-risk based leverage ratio to act as a credible supplementary measure to the risk-based capital requirements. This Basel III leverage ratio (LR) is defined as the capital measure (the numerator) divided by the exposure measure (the denominator) expressed in percentage: $LR_t = K_t/Exp_t$, where K denotes the Tier 1 capital and Exp the exposure measure at the end of the reporting period t.

The leverage ratio is intended to restrict the build-up of leverage in the banking sector to avoid destabilizing deleveraging processes that can damage the broader financial system and the economy and to reinforce the risk-based requirements with a simple, non-risk based "backstop" measure (Janda and Kravtsov, 2019). The exposure measure consists of the sum of the following exposures: on-balance sheet exposures (equivalent of the total assets); derivative exposures; securities financing transaction exposures and off-balance sheet items. Thus, Off-balance sheet (OBS) items are incorporated into the leverage ratio exposure measure (Merello, 2020). Basel Committee proposes the minimum Tier 1 leverage ratio > 3.00%. Banks must include all balance sheet assets in their exposure measure, including on-balance sheet derivatives collateral and collateral for SFTs. However, to ensure consistency, balance sheet assets deducted from Tier 1 capital may be deducted from the exposure measure. Liability items must not be deducted from the measure of exposure.

Under Basel III, banks are required to meet two new liquidity requirements: a 30-day liquidity asset ratio called the Liquidity Coverage Ratio (LCR) and a longer-term, structural liquidity ratio called

the Net Stable Funding Ratio (NSFR) (King, 2010). The LCR identifies the amount of unencumbered, high quality, liquid assets that can be used to offset cash outflows. The aim of the LCR is to ensure that banks have adequate funding liquidity to survive one month of stressed funding conditions. The NSFR addresses maturity mismatches between assets and liabilities. It establishes a minimum acceptable amount of stable funding based on the liquidity characteristics of a bank's assets over a one-year horizon. The quantity of available stable funding (the numerator in the ratio) must be greater than the required stable funding for these assets (the denominator). To meet the NSFR, banks are expected to hold more high-quality, liquid assets, financed by more stable deposits, more equity or longer maturity liabilities.

2.2. Theoretical literature review on the effectiveness of prudential rules

The first so-called Basel I prudential rules, adopted in 1997 to strengthen financial stability, are based on the Cooke ratio. These agreements take into account only the credit risk, then include the market risk in their amendment. In addition, the risk weights, which are rigid, are arbitrarily defined, taking no account of the real quality of the counterparty. This too narrow conception of banking risks creates an incentive for banks, under Basel 1, to finance risky borrowers. Another Basel I limit is the procyclicality of the Cooke ratio. Indeed, in a period of recession, the active constraint of required capital faced by banks experiencing a drop in their equity capital and making losses, leads to a sharp contraction in the supply of credit (Blum and Hellwig, 1995; Ferri, Liu, Stiglitz, 1999; Bernanke and Lown, 1991). Thus, faced with a constantly changing environment, the Cooke ratio fails to ensure the security, stability and soundness of banking activity (Pujal, 2003).

It was to overcome these limits that the Basel II rules were adopted in 2004. They are based on the Mc Donough ratio, which defines banking risk more precisely by integrating, in addition to credit risk, market risk and operational risk. Here, regulatory capital grows with the risk level of assets held by banks, leading them to reduce their holdings of riskier assets in response to rising regulatory capital. Banks are therefore no longer encouraged to grant credit to risky borrowers. The supply of credit to risky companies is smaller than that to low-risk companies (Artus, 2005a; Gennotte and Pyle, 1991).

Despite their interesting and precise approach which has led to great progress in the banking system, the Basel II accords have proved insufficient. First, the Basel II accords are considered too complicated. Indeed, many banks, unable to implement advanced risk measurement techniques, continued to use standard methods. Second, Basel II is more in line with the realities of developed countries. Emerging countries, which are not members of the Basel Committee, must put in place the preliminary reforms necessary for their implementation (Daoud, 2003). They therefore face higher implementation costs. The evaluation of operational risk suffers from an insufficiency linked to accessible data (Abbassi, 2007). Credit risk assessment can be tricky due to the lack of data available on debtor risk, or the lack of rating agencies (Hossain, 2012).

Also, the reality of Pillar 2 requires the existence of effective banking supervision, while developing countries often suffer from the absence of an effective supervisory authority (Frait and Tomsík, 2014). Therefore, the efforts that banks are making to improve their risk management and transparency are unnecessary, or do not lead to a reduction in regulatory capital. The Basel II accords also offer significant discretionary power to supervisors, thus creating a risk of corruption (Bailey, 2005). They also fail to reinforce the procyclical effect of prudential regulation. This procyclicality is linked to the fact that in a recession, the rating of banks deteriorates, increasing the intensity of the minimum capital constraint (Monfort and Mulder, 2000; Altman and Saunders, 2001). The procyclicality of capital rules is also due to the behavior of rating agencies, which is itself procyclical (Blume, Lim, Mackinlay, 1998).

Another limitation of Basel II, highlighted during the 2007-2008 global financial crisis, is that it increases bank liquidity risk. Indeed, the discriminating nature of the capital adequacy rule (higher capital requirement in the event of holding risky assets compared to holding non-risky assets) is likely to lead the bank to spontaneously choose to hold small amounts of liquidity reserves (Artus, 2011). It is to overcome these limits that the new 2010 Basel III standards introduce the notion of quality of equity in the calculation of the Mc Donough ratio and new rules to be observed concerning bank liquidity standards. Basel III capital ratios have been strengthened, making liquidity ratios necessary. While Basel II adds operational risk to Basel I (credit risk and market risk), Basel III introduces liquidity risk and strengthens the quality of banks' equity and their solvency. More precisely, these reforms which introduce a counter-cyclical cushion impose new constraints on banks: a new solvency ratio, three liquidity constraints and a leverage ratio, which aims to limit the leverage effect of banks.

The crisis has shown that some equity has more capacity to absorb losses than others. It is therefore a question of improving the quality of Tier 1 by allocating more capital of better quality to the most risky activities. With regard to the minimum requirement, the hard equity ratio is increased up to 7% through an increase in tier 1 which goes to 4.5% and the addition of a cushion or mattress of security of 2.5% (national regulators establish a counter-cyclical cushion ranging from 0% to 2.5% of the capital). Made up of results put in reserve during the high cycle, the cushion would be used in the event of a crisis and immediately reconstituted during a period of growth. This gives a solvency ratio equal to 10.5% and not 8% as required by Basel II.

Another reform of Basel III is the implementation of two other liquidity ratios in order to improve liquidity risk management. We have the Liquidity Coverage Ratio (LCR), which consists for a bank to have liquidity reserves greater than the net cash outflows so that it can survive, in the event of a crisis with its liquidity for 1 month. The objective of the Net Stable Funding Ratio (NSFR) is to keep the amount of stable funding higher than the amount of stable funding required so that the institution can operate for one year in a context of crisis. Basel III liquidity ratios force banks to hold more liquidity than they would spontaneously do. This strengthens the capacity of the banking system to absorb shocks resulting from financial and economic stresses.

Basel III sets up a leverage ratio (ratio of the bank's equity to total assets) at 3%. This ratio aims to force shareholders who often have an interest in their company increasing its debt in order to invest in profitable assets rather than increasing their capital. This behavior had the effect, during the crisis, of the mass cession on the markets of the least profitable assets when their value fell sharply, thus amplifying the spiral of losses. Finally, Basel III recommends prevention against systemic risks.

The Basel III requirements have been introduced after the global financial crisis during which we have witnessed a build-up of excessive on- and off-balance sheet leverage in the banking system. In many cases, banks built up excessive leverage while apparently maintaining strong risk-based capital ratios. At the height of the crisis, financial markets forced the banking sector to reduce its leverage in a manner that amplified downward pressures on asset prices. This deleveraging process exacerbated the feedback loop between losses, falling bank capital and shrinking credit availability (BCBS, 2014). The Basel III framework introduced a simple, transparent, non-risk based leverage ratio to act as a credible supplementary measure to the risk-based capital requirements. This Basel III leverage ratio (LR) is defined as the capital measure (the numerator) divided by the exposure measure (the denominator) expressed in percentage: $LR_t = K_t/Exp_t$, where K denotes the Tier 1 capital and Exp the exposure measure at the end of the reporting period t.

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Under Basel III, banks are required to meet two new liquidity requirements: a 30-day liquidity asset ratio called the Liquidity Coverage Ratio (LCR) and a longer-term, structural liquidity ratio called the Net Stable Funding Ratio (NSFR) (King, 2010). The LCR identifies the amount of unencumbered, high quality, liquid assets that can be used to offset cash outflows. The aim of the LCR is to ensure that banks have adequate funding liquidity to survive one month of stressed funding conditions. The NSFR addresses maturity mismatches between assets and liabilities. It establishes a minimum acceptable amount of stable funding based on the liquidity characteristics of a bank's assets over a one-year horizon. The quantity of available stable funding (the numerator in the ratio) must be greater than the required stable funding for these assets (the denominator). To meet the NSFR, banks are expected to hold more high-quality, liquid assets, financed by more stable deposits, more equity or longer maturity liabilities.

2.3. Empirical literature review on the effectiveness of prudential rules

Shrieves and Dahl (1992) developed one of the first empirical studies of the Basel I rules applied to developed countries. Using a model with two simultaneous equations, with data from 1800 American banks between 1983 and 1987, they assess the impact of the capital requirements proposed by Basel I on banks' risk-taking after the implementation of the capital ratio leverage (equity / total assets). They obtain a positive relationship between changes in risk and changes in capital, both for under-capitalized banks and for banks with a level of capital greater than the minimum required. In other words, Basel 1 induces an increase in risk taking by the banks.

This study served as a support for many other studies, such as that of Jacques and Nigro (1997). The latter estimate a simultaneous equation model using the triple least squares method in order to determine the relationship between capital and risk taking. The study is carried out on 2570 American commercial banks from 1990 to 1991. The results obtained show a negative relationship between changes in capital and risks, thus confirming the incentive of Basel I to take excessive risk by banks. Other empirical studies have shown that this risk-taking can be mitigated by the credible threat of sanctions. This is the case with the study carried out by Aggarwal and Jacques (2001) and Rime (2001). These are inspired by the simultaneous equation model of Shrieves and Dahl (1992) and introduce sanctions variables to study the impact of Basel I on risk taking and bank capital.

The study by Rime (2001) concerns a sample of 154 Swiss banks from 1989 to 1995 and that of Aggarwal and Jacques (2001), on a sample of 1,685 American banks, between 1990 and 1997. They show that the penalties incurred by banks in the event of non-compliance with the requirements set by the regulator, leads to an increase in the capital ratio without affecting banks' risk-taking. These sanctions have had a positive impact on the behavior of banks in that they can neutralize the incentive effect of Basel I in terms of risk taking.

Other empirical studies focus on Basel II in developed countries. Thus, Delis and Staikouras (2011) examine the relationship between the effectiveness of Basel II and banking risk, for a sample of 17 developed countries, over the period from 1998 to 2008. They approximate bank failure by a Z-score deduced from the scoring method, while the on-site audit and sanctions measure surveillance. They highlight a non-linear and inverse relationship between on-site audits and banking risk, and a negative linear relationship between sanctions and risk. This means that the strengthening of supervision under Basel II makes it possible to reduce the exposure of banks to risks.

The effectiveness of Basel III rules has also been the subject of empirical studies in developed countries. Levy-Garboua and Maarek (2014) study, using the simplex algorithm method in operations research, the effect of Basel III on the balance sheets of banks in the euro zone. Their results show a significant contraction of the balance sheet, the total disappearance of credit and repos and the absence of the need for medium-term market financing. This, although the rate on loans is significantly higher than the yield on securities. Restoring a normal banking structure, with credit and securities, requires increasing the yield on credit. In this case, the stock of securities and repos then drops drastically.

Emerging and developing countries have also been the target of empirical studies on the effectiveness of prudential rules. Klomp and Haan (2013) examine the impact of banking regulation and supervision on banking risk. They are based on a sample of around 400 banks from 70 developing and emerging countries between 2002 and 2008. Regressing a dynamic panel model, they conclude that the strengthening of regulation and supervision under Basel II reduces banking risk. This risk reduction is all the greater depending on the nature of the banks (size, ownership structure, etc.).

Figuet, Humblot and Lahet (2013) highlight the negative impact of the Basel III agreements on bank financing in emerging countries. They analyze the flows of bank capital from banks in 16 industrialized countries to a set of 30 emerging countries, over a period of 1999-2010. The results obtained show that the profitability constraint of banks occupies an important place in the management of their balance sheets and the granting of credit. Also, liquidity ratios present a major threat to the granting of credit in emerging countries.

Empirical studies on the effectiveness of the Basel rules also concern the WAEMU countries. They have never really applied the Basel II measures because the need to strengthen solvency ratios in order to reduce the supply of credit to excessively risky projects does not seem necessary because this zone is characterized by strong economic uncertainties and institutions which de facto contract the supply of credit. Before adopting Basel III, UEMOA applied an adaptation of Basel I. Dannon and Lobez (2014) analyze the effect of Basel I on the risk of failure of WAEMU banks using a fixed effects panel model for the period 2000-2010. Their results show that the risk of bank failure is low when they have high solvency ratios, with large size, when lending is their main activity and under favorable macroeconomic conditions.

Ndiaye (2014) studies the relationship between the probability of failure of 98 banks in the WAEMU zone and micro and macroeconomic variables of the countries in which they are based, over the period 2001-2011. Focusing only on the large banks included in the sample, he uses the Z-Score according to the Roy (1952) approach as an indicator of bankruptcy. Then, he uses the Generalized Moments Method (GMM) in dynamic panel, to show that the application of the capital requirements recommended by the Basel I agreements leads to a decrease in the risk of bankruptcy of WAEMU banks, whether they are large size or not.

Empirical studies have also assessed the effectiveness of Basel III rules in developing countries, and particularly in WAEMU. Finactu (2018), a consulting firm, analyzes the consequences of Basel

III on customers and banks in the franc zone. The results they obtain show that Basel III will have complex effects, generally positive in the long term, but with significant collateral damage in the short term. Indeed, the application of Basel III rules will be very costly in the short term. Then, in the medium term, we will see the disappearance of the banks (the weakest), having been unable to mobilize the capital imposed on them by regulation. Finally, in the long term, banks will make significant efforts, in the face of the sophistication of banking activity, to generate profitability.

The work reviewed shows the ambivalent effects of Basel III on the behavior of banks, which requires great caution when implementing it. Thus the Basel III standards, which have positive effects on financial stability, nonetheless have unwanted effects and shortcomings. It is about studying the real impact of Basel III on the banking system of developing countries, in particular that of WAEMU. More specifically, we study the effect of this regulation on the intermediation and market activities of banks in the zone. Since Basel III forces WAEMU banks to hold more liquidity and requires a strengthening of solvency ratios, one might expect these prudential rules to tend to further reduce the supply of credit in the WAEMU economy than under Basel II. This could raise doubts about the relevance of Basel III for WAEMU. According to this previous available literature, we derive the following research hypotheses:

- Hypothesis 1: Basel III has a negative effect on loans and deposits (intermediation activities)
- Hypothesis 2: Basel III has a negative effect on securities placements, market debt and repos (market activity).

3. Empirical methodology: model specification, description of the variables and presentation of the linear programming method

Our methodological approach uses operational research to determine the optimal values of the various balance sheet items of WAEMU banks under the constraints of Basel III. It is inspired by the theoretical and empirical framework developed by Levy-Garboua and Maarek (2014). They use a model for optimizing the return on equity (ROE) of a representative bank, under balance sheet constraint and Basel III regulatory constraints, to analyze the effect of Basel III on the behavior of banks in the euro area. We adapt this method to a sample made up of WAEMU banks.

To assess the effect of Basel III (entered into force in the WAEMU on January 1, 2018) on the intermediation and market activities of WAEMU banks, we first determine the theoretical values of the bank balance sheet items, obtained through the optimization program of the representative bank. These optimal values reflect the effect of Basel III on the various assets and liabilities of the WAEMU bank balance sheet. We then compare these theoretical values with the values observed before the implementation of Basel III, i.e. the data for 2017.

3.1. Specification of the theoretical optimization model

The basic accounting equation states that Assets are equal to Liability plus Equity. The balance sheet of the WAEMU representative bank is as follows:

Asset	Liabilty + Equity
Loans $(\boldsymbol{L})$	Equity (FP)
• Short term $(\boldsymbol{L_S})$	Market debt (DM)
• Intermediate $(\boldsymbol{L_i})$	Deposit (D)
• Long term $(\boldsymbol{L_l})$	Repos $(Repo)$
Securities $(\boldsymbol{S})$	Refinancig (RF)
Reserves $(\boldsymbol{Res})$	

On the asset side, the bank holds loans L, securities S and reserves Res. To formalize the regulatory constraints, a distinction is made between loans according to their residual maturity: short-term credit, less than a month (L_s), intermediate credit, between one month and one year (L_i) and long-term loans, more than one year (L_l). Suppose that :

$$L_s = a_1 L \quad \text{with } 0 \leq a_1 \leq 1 \quad (1)$$
$$L_i = a_2 L \quad \text{with } 0 \leq a_2 \leq 1 \quad (2)$$
$$L_l = (1 - a_1 - a_2)L \quad (3)$$

On the liabilities side, the bank finances its assets through its own funds (FP), medium-term market debt (DM), deposits (D), wholesale or repos[2] ($Repo$), secured by securities and refinancing with of the central bank (RF). In addition, there are guarantees given and back-up credit lines that can be mobilized at the initiative of the client, for an off-balance sheet (HB).

3.1.1. Formulation of the objective function

The bank's objective is to maximize the profitability of its equity, ROE which is written as the ratio of net income to total equity. This assumption is all the more relevant as in the context of financial globalization, WAEMU banks, like those in the world, have an objective of optimizing their shareholder value.

Noting r_L,r_S, r_{es},, r, r_D, r_{DM} and r_f interest rates on loans, securities, reserves, repos, deposits, market debt and refinancing respectively with $r_L \geq r_{DM} \geq r_S \geq r_D$; $r \geq r_f \geq r_{es}$, and C the operating costs of the bank, the return on equity (ROE) is written as the ratio of net income to shareholder's equity[3]:

$$ROE = \frac{\left[r_L L + r_S S + r_{es} Res - r_D D - r_{DM} DM - r Repo - r_f RF - C\right]}{FP} \quad (4)$$

The bank maximizes its ROE by taking into account the constraints weighing on it: the balance sheet constraint and regulatory constraints.

[2] A repo is a two-step transaction, in which two parties make an agreement. The first step is to sell a security for cash to a counterparty, then buy it back on a predetermined date and price.

[3] ROE measures the amount of profit per unit of shareholder's equity in a given year.

3.1.2. Balance sheet constraint and regulatory constraints

The bank's balance sheet constraint simply traces the accounting balance whereby the total assets of the bank balance sheet equals total liabilities plus equity.

- ✓ **Balance sheet constraint**

It is written :

$$L + S + Res = FP + DM + D + Repo + RF \quad (5)$$

Regulatory constraints are those imposed by the regulator through prudential rules.

- ✓ **Solvency constraint**

According to this constraint, equity must be at least equal to a fraction of the weighted average assets. By noting k and k' the regulatory coefficients for credits and securities, e' the fraction of securities admitted as collateral and h' the required haircut on repos, this constraint is written:

$$FP > kL + k'\left[S - e'\left(\frac{S - Repo}{1 - h'}\right)\right] \quad (6)$$

The coefficient k' applies to securities which are not admitted as high quality liquid assets (HQLA).

- ✓ **Short-term liquidity constraint**

This short-term liquidity coverage ratio (LCR) constraint is expressed through the following five equations:

$$Q + CI \geq CO \quad (7)$$
$$CI = \gamma_1 L_c + \gamma_2 L_i + \gamma_3 S \quad (8)$$
$$CO = \alpha_1 D + \alpha_2 Repo + \alpha_3 HB \quad (9)$$
$$Q \geq h\, CO \quad (10)$$
$$Q = (Res - gD) + eS \quad (11)$$

In (7), the sum of high quality liquid assets (HQLA) denoted Q, and capital inflows denoted CI, must be greater than or equal to the capital outflows denoted CO.

Equation (8) defines the capital inflows CI, and equation (9) the capital outflows CO, assessed in a stressful situation by the regulator which imposes the coefficients on the banks $\gamma_1, \gamma_2, \gamma_3$ for CI and $\alpha_1, \alpha_2, \alpha_3$ for CO). It should also be noted that the reimbursement of RF is not considered as a cash outflow by the regulator.

Equation (10) indicates that high quality liquid assets, Q must be greater than or equal to $h = 25\%$ of capital outflows CO. Equation (11), for its part, recalls that Q (high quality liquid assets) is equal to the sum of the excess reserves (beyond the minimum reserves requirements which are a fraction g of the deposits) and of the qualified securities (eS).

- ✓ **Long-term liquidity constraint**

This constraint on the long-term liquidity ratio (net stable funding ratio or NSFR) requires that long-term commitments (loans over one year plus a fraction μ of securities with a maturity exceeding one year and a fraction η_2 of "off-balance sheet" commitments HB that could be drawn) must be less than the resources for more than one year (equity, market debt and a η_1 proportion of deposits considered to be very stable). It is written:

$$L_1 + \mu S + \eta_2 HB < FP + DM + \eta_1 D \qquad (12)$$

- ✓ **Leverage ratio constraint**

Equity must represent more than 3% of all assets plus a fraction β of "off-balance sheet" items:

$$FP > I(L + S + Res + \beta HB) \qquad (13)$$

It is furthermore made the ad hoc assumption that "off-balance sheet" transactions, mainly guarantees given by the bank and commitments of emergency lines of credit, are in general closely linked to long-term credit ; u being the proportion of credit that could theoretically be drawn by customers, we have:

$$HB = uL_1 \qquad (14)$$

3.1.3. The representative bank optimization program

We assume that the bank, price-taker, adapts in a context of rates that are imposed on it. Neutral to risk, it maximizes the return on its equity under the balance sheet constraint, the Basel III regulatory constraint and the positivity constraints. We also assume that in the short term, the bank's equity is constant, ie $FP = \overline{FP}$. This assumption is all the more realistic since even before the Basel III rules were implemented in WAEMU, banks, anticipating the increase in regulatory capital, increased their capital.

According to Cabinet Finafrique (2018), at the end of December 2016, banks in the WAEMU zone held a level of equity corresponding to 11% of their weighted risks, i.e. above the overall threshold of 8.625% provided for by the new prudential standards (against a threshold of 10.5% advocated by the Basel Committee). We can thus consider that the banks' own funds in 2017 before Basel III did not vary in 2018 after the application of the new standards[4].

Assuming the constancy of equity also obeys a technical issue. Indeed, in this case, the objective function and the constraints all become linear and the resolution of the optimization program can be done by the technique of linear programming. The bank's complete program, defining its balance under Basel III, is as follows:

[4] It is only in the medium term that they will substantially change their own funds since by 2022, Basel III in the WAEMU foresees a target of 11.5% of weighted risks as the minimum level of capital.

$$
\begin{cases}
\text{MAX}\left[r_L L + r_S S + r^* Res - r_D D - r_B DM - (rRepo) - r_f RF - C\right]/\overline{FP} \\
L + S + Res = \overline{FP} + DM + D + Repo + RF \\
\overline{FP} > kL + k'\left[S - e'\left(\frac{S - Repo}{1 - h'}\right)\right] \\
Q + CI \geq CO \\
CI = \gamma_1 L_c + \gamma_2 L_i + \gamma_1 S \\
CO = \alpha_1 D + \alpha_2 Repo + \alpha_3 HB \\
Q \geq h\, CO \\
Q = (Res - gD) + eS \\
L_1 + \mu S + \eta_2 HB < \overline{FP} + DM + \eta_1 D \\
\overline{FP} > I(L + S + Res + \beta HB) \\
HB = uL_1 \\
L \geq 0; S \geq 0;\ Res \geq 0;\ D \geq 0;\ MD \geq 0;\ Repo \geq 0;\ RF \geq 0;\ y > 0
\end{cases}
$$

3.2. Description of data and optimization technique

3.2.1. Data source

The data we need relate to equity FP, operating costs C, all nineteen (19) regulatory parameters k, k', e, e', h, h', γ_1, γ_2, γ_3, α_1, α_2, α_3, g, μ, η_1, η_2, I, β, u and all seven (7) interest rates r_L, r_S, r^*, r_B, r, r_D and r_f.

To establish the observed values of the assets and liabilities of the bank balance sheet before the entry into force of Basel III in the WAEMU, we favor the data for 2017 (average data). Regarding equity and operating costs to be included in the optimization program, we choose data for 2018 corresponding to the entry into force of Basel III. Data on equity and operating costs are taken from the income statement of all WAEMU banks from annual reports of the BCEAO, reports on bank conditions, and annual statistical bulletins published by the BCEAO. Operating costs are approximated by the sum of general operating expenses and other banking operating expenses.

Data on interest rate is for 2018 and is taken from the BCEAO databases. Data on regulatory coefficients are obtained by referring to the coefficients used in WAEMU. The interest rates are obtained by the calibration technique which makes it possible to have a reasonable rate structure for the WAEMU zone. The refinancing rate is roughly equal to the sum of the rates on banking operations and the marginal rate of liquidity injections by BCEAO calls for tenders; the market rate is approximated by the rate on treasury bills.

3.2.2. Optimization technique: linear programming by the simplex algorithm

As a tool to aid decision, linear programming is a method of determining the optimal course of action to achieve given objectives, using limited resources (Dorfman, Samuelson and Solow, 1958). It consists in optimizing a linear objective function, under linear constraints, in the form of an unequation or equation. Decision variables must be positive. This program is solved by the simplex algorithm developed by Dantzig (1947).

This method shows that the optimum (x), if it exists, is a vertex of the polyhedron K defined by the set of linear inequalities $K = \{x: Ax = b. x \geq 0\}$. This result allowed Danzig (op. cit.) to propose the simplex algorithm whose idea consists of starting from any vertex of K and to select,

at each iteration, a neighboring vertex for which the function decreases by the pivot method. This program is transformed into the standard form by introducing a deviation variable y. First, we find a starting vertex among the vertices of the possible polyhedron.

We start with an obvious solution. The variables of non-zero values form the base, the other variables are said to be off-base. Second, we express each constraint as a function of a single base variable and off-base variables. By noting s_i the value of the corresponding base variable and Δ_j the coefficient of the variable j in the objective function, we obtain another table. The simplex algorithm consists of modifying the following table, i.e. changing the vertex, in order to increase the objective function. It proceeds as follows:

(1) Choice of the variable $\bar{j}$ entering the base : $\bar{j}$: $min_j \Delta_j = \Delta_{\bar{j}}$

(2) Choice of the variable $\bar{\imath}$ leaving the base : $\bar{\imath}$: $min_i \left(\frac{s_i}{a_{i\bar{j}}} \geq 0 \right) = \frac{s_{\bar{\imath}}}{a_{\bar{\imath}\bar{j}}}$

(3) Determination of the new base solution (pivot operation):

- $a_{\bar{\imath}\bar{j}}$ is called the pivot. We transform the line corresponding to the variable $\bar{j}$ by dividing it by the pivot. The new value of $a_{\bar{\imath}\bar{j}}$ is 1.
- For the variable $\bar{j}$ to be a base variable, we must have $a_{i\bar{j}} = 0$ for $i \neq j$. We then obtain :

$$a_{ij} \leftarrow a_{ij} - a_{i\bar{j}} \times a_{\bar{\imath}j}$$

- To obtain $\Delta_{\bar{j}} = 0$, we proceed in the same way for the objective-function:

$$\Delta_j \leftarrow \Delta_j - \Delta_{\bar{j}} \times a_{\bar{\imath}j}$$

(4) We repeat rules (1), (2) and (3) until $\Delta_j \geq 0$ for all j.

4. Results and discussion

4.1. Optimization

We recall that the variables to be optimized are $L, S, Res, D, DM, Repo, RF$. Solving the program requires assigning numerical values to the various regulatory coefficients and interest rates. We summarize these numerical values in the tables below:

Table 1: Basel III regulatory coefficients in WAEMU

Coefficient	Short description	Value
$\boldsymbol{k}$	Regulatory coefficient for loan	8%
$\boldsymbol{k'}$	Regulatory coefficient for securities	10%
$\boldsymbol{e}$	Proportion of securities in high quality liquid assets	0.1
$\boldsymbol{e'}$	Fraction of securities admitted as collateral	0.5
$\boldsymbol{h}$	Proportion of capital outflows	0.25
$\boldsymbol{h'}$	Required haircut on repos	4%
$\boldsymbol{u}$	Proportion of credit drawn by customers	0.4
$\boldsymbol{\mu}$	Fraction of securities with a maturity exceeding one year	0.25
$\boldsymbol{\beta}$	Fraction of « off-balance sheet » items	0.3
$\boldsymbol{\gamma_1}$	Coefficient on the banks for capital inflows	0.5
$\boldsymbol{\gamma_2}$	Coefficient on the banks for capital inflows	0.5
$\boldsymbol{\gamma_3}$	Coefficient on the banks for capital inflows	1.0
$\boldsymbol{\alpha_1}$	Coefficient on the banks for capital outflows	0.05
$\boldsymbol{\alpha_2}$	Coefficient on the banks for capital outflows	0.8

α_3	Coefficient on the banks for capital outflows	0.15
I	Fraction of assets	3%
g	Fraction of deposits as reserves requirement	2%
η_1	Proportion of deposits considered to be very stable	0.67
η_2	Fraction of "off-balance sheet" commitments	0.05

Source : BCEAO (2018)

Table 2: Interest rates in WAMEU in 2018

Interest rates	Short description	Value
r_L	Interest rates on loans	6.79%
r_S	Interest rates on securities	4.5%
r_{es}	Interest rates on reserves	3%
r_D	Interest rates on deposits	5.41%
r	Interest rates on repos	0.5%
r_{DM}	Interest rates on market debt	5.90%
r_f	Interest rates on refinancing	9.72%

Source : the author, from BCEAO database (2018)

We calculate that the operating costs, as approximated in our study, give:
C = General charges of $exploitation$ + Others bank $charges$ of $exploitation$
C = 3250 + 12496 = 15746 (in million CFA francs)
Equity in 2017 gives: FP = 3105.23 billion CFA francs

Applying the simplex algorithm to the optimization program (appendix A1) gives a succession of iterations which ultimately leads to the following optimal solution:
$Z = ROE = 0.99$ with $L = 35\,907\,518.99$; $S = 65\,230\,151.42$; $Res = 0$; $D = 0$; $DM = 33\,346\,429$; $Repo = 64\,686\,014.40$; $RF = 0$

We summarize the comparison between the balance sheet items before Basel III (observed values) and after Basel III (theoretical or optimal values). As the absolute values of the optimization do not provide interesting and comparable results, it would be interesting providing ratios, as of for example the data of every element to total assets, in order to analyze the structure of the balance sheet.

Table 3: Effects of Basel III on the balance sheet of the WAEMU banking system

Balance sheet items		Before Basel III (million CFA francs and in %)	After Basel III (million CFA francs and in %)
Asset	Loans (L)	23 736 739 (51.3%)	35 907 518.99 (35.5%)
	Securities (S)	3 951 671 (8.5%)	65 230 151. 42 (64.5%)
	Reserves (Res)	18 574 000 (40.2%)	0
Liability + Equity	Market debt (DM)	11 779 (0.03%)	33 346 429 (32.97%)
	Deposits (D)	28 081 743 (60.7%)	0
	Repos $(Repo)$	5 365 091 (11.6%)	64 686 014.40 (63.96%)
	Refinancing (RF)	9 698 570 (20.96%)	0

	Equity (FP)	3 105 227 (6.71%)	3 105 227 (3.07%)

Source: the author, based on the results of the linear optimization program

The simulation carried out within the framework of the WAEMU banking system shows that with a structure of reasonable rates, the following results are obtained:

Table 4: Theoretical effect of Basel III on the ROE of the banking system

	Before Basel III	After Basel III
ROE (relative value)	0.1350	0.9923
ROE (percentage)	13.5%	99.23%

Source: the author, based on data from the BCEAO

Note: ROE is the ratio of net income to equity. In 2017, the net income of the entire WAEMU banking system amounted to 419.5 billion CFA francs while equity stood at 3,105.23 billion CFA francs.

We obtain, among other things, the counterintuitive result that $Res = 0$, $D = 0$; $RF = 0$, and $ROE = 99\%$. This appears as a weakness of the analysis. The model mathematically reaches that little realistic result, because the model is independent to the demand in the market, among others. For avoiding this, we present also an alternative model where some restrictions guaranteeing $Res > 0, D > 0;\ RF > 0$ are included. These restrictions relate to hypotheses about banks in Africa.

In the initial model, we assumed that banks are price takers. On the contrary, assuming that banks in Africa are price makers[5] allows us to model interest rates in terms of inverse demand (loan, bond) and to introduce decreasing returns. If not, a maximizing bank will always allocate all its resources to the most profitable activity, which is lending. The next most profitable activity is securities holdings, which banks are required to hold for regulatory purposes. Without decreasing returns, the model can reach Res, D and RF being equal to zero. Assuming price makers banks and decreasing returns are some restrictions guaranteeing $Res > 0, D > 0;\ RF > 0$. Introducing those conditions in the optimization program (appendix A2) leads to the following optimal solution:

$Z = ROE = 19.25\%$ with $L = 27\,546\,604$; $S = 58\,334\,916.4$; $Res = 15\,256\,150$; $D = 18\,235\,000$; $DM = 15\,111\,429$; $Repo = 55\,561\,891.40$; $RF = 9\,124\,123$

We summarize the comparison between the balance sheet items before Basel III (observed values) and after Basel III (theoretical or optimal values) in the table below:

Table 5: Effects of Basel III on the balance sheet of the WAEMU banking system

Balance sheet items		Before Basel III (million FCFA and as percentage of total assets or total liabilities)	After Basel III (million FCFA and as percentage of total assets or total liabilities)
Asset	Loans (L)	23 736 739 (51.3%)	27 546 604 (27.24%)
	Securities (S)	3 951 671 (8.5%)	58 334 916.4 (57.68%)
	Reserves (Res)	18 574 000	15 256 150

[5] It is not reasonable to assume that banks in Africa are price takers. For Khemraj (2006), in developing countries, the financial sectors are largely dominated by banks, banking concentration is also a leading feature. The banking sector is oligopolistic. In these markets, buyers (mainly banks) are very few in number, so they have market power. It is therefore precisely oligopsonies on which the banks determine the interest rate of the public securities offered.

		(40.2%)	(15.08%)
Liability + Equity	Market debt (DM)	11 779 (0.03%)	15 111 429 (14.94%)
	Deposits (D)	28 081 743 (60.7%)	18 235 000 (18.03%)
	Repos $(Repo)$	5 365 091 (11.6%)	55 561 891.40 (54.94%)
	Refinancing (RF)	9 698 570 (20.96%)	9 124 123 (9.02%)
	Equity (FP)	3 105 227 (6.71%)	3 105 227 (3.07%)
	ROE	13.5%	19.25%

Source: the author, based on the results of the linear optimization program

We check that the balance sheets before and after Basel III are balanced, with the total assets equal to the total liabilities. In addition, we observe, with the application of Basel III, the following results:

- ✓ Banks increase their credit volume $(\Delta L = 3\,809\,865)$ as well as the value of their securities $(\Delta S = 54\,383\,245.4)$ but decrease their reserves $(\Delta Res = -3\,317\,850)$;
- ✓ Banks are financed mainly through equity and with increasing resources: repos and market debts. The amount of repos increased $(\Delta Repo = 50\,196\,800.4)$; that of market debts also increased $(\Delta DM = 15\,099\,650)$;
- ✓ Banks are also financed with decreasing resources: deposits from the public and refinancing by the central bank or the interbank market $(\Delta D = -9\,846\,743;\ \Delta RF = -574\,447)$;
- ✓ The ROE goes from 13.5% to 19.25%.

4.2. Robustness check of the results

In addition, as a robustness test of the results, we repeat the analyses considering first the average data for 2017-2018, and then by changing the year. We obtain the following table:

Table 6: Effects of Basel III on the balance sheet of the WAEMU banking system

Balance sheet items		After Basel III (considering the year 2018)	After Basel III (considering average date for 2017-2018)	After Basel III (changing the year : 2019)
Asset	Loans (L)	27 546 604 (27.24%)	27 451 025 (27.14%)	25 452 785 (25.17%)
	Securities (S)	58 334 916.4 (57.68%)	54 632 452 (54.02%)	56 452 863 (55.82%)
	Reserves (Res)	15 256 150 (15.08%)	19 054 193.4 (18.84%)	19 232 022 (19.01%)
Liability + Equity	Market debt (DM)	15 111 429 (14.94%)	15 541 231 (15.37%)	15 965 563 (15.78%)
	Deposits (D)	18 235 000 (18.03%)	17 421 563 (17.22%)	17 584 542 (17.39%)
	Repos $(Repo)$	55 561 891.40 (54.94%)	55 124 563 (54.50%)	54 696 926 (54.08%)
	Refinancing (RF)	9 124 123 (9.02%)	9 945 086 (9.83%)	9 785 412 (9.68%)
	Equity (FP)	3 105 227 (3.07%)	3 105 227 (3.07%)	3 105 227 (3.07%)

ROE	19.25%	18.74%	19.06%

Source: the author, based on the results of the linear optimization program

We note that, in general, the results are robust to the change of date, except for Reserves: increase in Loans, Repos, Securities, market debts; decrease in Deposits, Refinancing. By changing the date, the effect of Basel III on Reserves become more intuitive. We obtain an increase in Reserves.

4.3. Interpretation and discussion of the results

Basel III has the effect of increasing the credit supply in WAEMU. This result differs from that obtained by Figuet, Humblot and Lahet (2013) for emerging countries and that of Levy-Garboua and Maarek (2014) for the euro zone. The latter even find, at first, a cancellation of the credit offer. Then, reestablishing a normal bank structure with credit requires, after a period of adaptation, to increase the return on credit, so that in the long term equilibrium, he ends up with an increase in the cost of credit and a contraction in the credit supply. For the WAEMU zone, Finactu (2018) had highlighted the possibility that the increased capital requirement in Basel III could push the banks in the zone to refuse to take additional risks and to reduce their loans to the economy, up to their equity. But our results show that it is obvious that the adaptation of Basel III to the realities of the WAEMU makes it possible to better finance the economies of this zone, in accordance with the objectives of the BCEAO.

In addition, under Basel III, banks are experiencing a decline in deposits and refinancing (financing from the central bank or on the interbank market). This decrease of deposits and bank refinancing results from the tendency of Basel III to make the collection of deposits and the use of refinancing less profitable. In fact, Basel III aims to increase bank liquidity by making it increasingly difficult for banks to transform deposits, essential in the short term (assumed to be unstable), into medium and long term uses. In addition, the need for more liquidity can easily lead to the demand for refinancing being superior to the supply, which tends to make this refinancing more expensive.

On the other hand, banks are encouraged to obtain their resources from market debts and repos. This increase in repos (acquisition of liquidity against sale of securities) is the result of the obligation for banks to increase their liquidity under Basel III. Banks are therefore led to sell part of their securities for cash with the idea of redeeming them forward at a date and price agreed in advance. The increase in banks' market debt is linked to the fact that in the short term, banks hardly modify their equity, which, as of the end of December 2016, are already above the overall threshold of 8.625% of risk-weighted risks, provided for by Basel III from its implementation on January 1, 2018 (Finafrique, 2018). Banks therefore prefer to increase their level of indebtedness, thus increasing their financial leverage, especially since the leverage ratio set at 3% by the Basel Committee is not applied in the WAEMU. Such an increase in indebtedness increases the ROE of banks, which they are precisely aiming for.

The resources thus mobilized by the WAEMU banks are used not only to finance the increase in loans but also to increase the placement of securities on the financial markets. This increase in investments under Basel III can be explained as follows: the increase in repos certainly allows banks to have liquidity, but the flexibility of the maturities (varying from 1 day to 1 year) of these repos gives them wide variety of possibilities to invest this liquidity at different maturities. They therefore increase their purchases of securities, especially government securities which provide a considerable advantage in terms of risk and return. Finactu (2018) shows that WAEMU banks allocate a very large share of their resources to domestic government securities, compared to banks around the world. We note a percentage of assets of 20.47% for the WAEMU zone, against 5.54% of banking assets in the euro zone, 12.94% for Latin America and the Caribbean, etc.

The result of an increase in reserves is in line with Basel III, which is supposed to force banks to increase their liquidity. In summary, banks in the WAEMU tend, under the effect of Basel III, to abandon pure intermediation activities (collecting deposits and granting loans) in favor of market activities (sale of securities via repos, placement of securities). Banks are increasing their supply of credit, not only from deposits and bank refinancing but also via resources from the financial markets. By simultaneously achieving increased financing of economies and strengthening bank liquidity in WAEMU, Basel III is adapted to the realities of WAEMU economies.

5. Final Remarks

In this paper, we have studied the effect of Basel III adapted to WAEMU on the behavior of commercial banks in the zone (intermediation activities and market activities). The methodology used is that of operations research, in particular linear programming via the Danzig simplex algorithm. This technique allowed us to solve a program to optimize the return on bank equity, under various constraints (balance sheet constraints, Basel III regulatory constraints), and with a reasonable rate structure and to obtain the optimal values of the various bank balance sheet items. These theoretical values were then compared with the values observed before Basel III.

The results show an increase in the supply of credit, a decrease in bank deposits. Our first research hypothesis is therefore verified only for deposits. Basel III has a positive effect on loans and a negative effect on deposits of WAEMU banks (intermediation activities). The results obtained also show that the Basel III agreements help to considerably increase the value of securities, repos and market debt (market activities). This result confirms our second research hypothesis. The market activities of WAEMU banks are therefore experiencing remarkable growth with the application of Basel III standards. In fact, the increase in bank financing is obtained not only from deposits and bank refinancing but also via resources from the financial markets.

We can also observe the intuitive result of an increase of bank reserves in line with the constraint that Basel III imposes on banks to increase their liquidity. In short, Basel III tends to strengthen bank financing in the zone, while improving the soundness of banks through the constitution of larger reserves. This is in line with the objectives of the BCEAO which are, among others, to allow WAEMU banks to be better equipped to manage risks and to benefit from the banks' financial health, allowing them to finance more the economies of the zone (Mbow, 2018). The results obtained are important in that they give a general perspective of the effects of Basel III, but their scope must be qualified, however, because they are based on a calibration which is certainly reasonable but not indisputable of prudential ratios and interest rates. We reserve this question of checking more robustness for our results for further study.

Declaration

Conflicts of interest: The author declares that he has no conflict of interest.

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Appendix A1

We simplify the optimization program, we obtain the following final program:

$$\begin{cases} \underset{L,S,Res,D,DM;Repo,RF}{\text{MAX}} \left[r_L L + r_S S + r_{es} Res - r_D D - r_{DM} DM - (rRepo) - r_f RF - C\right]/\overline{FP} \\ L + S + Res = \overline{FP} + DM + D + Repo + RF & (1) \\ FP > kL + k'\left[S - e'\left(\frac{S - Repo}{1 - h'}\right)\right] & (2) \\ Q + CI \geq CO & (3) \\ CI = \gamma_1 L_c + \gamma_2 L_i + \gamma_1 S & (4) \\ CO = \alpha_1 D + \alpha_2 Repo + \alpha_3 HB & (5) \\ Q \geq 0{,}25\, CO & (6) \\ Q = (Res - gD) + e'S & (7) \\ L_l + \mu S + \eta_2 HB < \overline{FP} + DM + \eta_1 D & (8) \\ FP > I(L + S + Res + \beta HB) & (9) \\ HB = u L_l & (10) \\ L \geq 0; S \geq 0;\ Res \geq 0;\ D \geq 0;\ MD \geq 0;\ Repo \geq 0;\ RF \geq 0; & (11) \end{cases}$$

Substitute the equations (4), (5), (7) and (10) in the equation (3), and the equations (7), (5) and (10) in the equation (6). Then, knowing that $L_s = a_1 \mathrm{L}\,; L_i = a_2\,\mathrm{L}\,; L_l = \left(1 - a_1 - a_2\right)\mathrm{L}$, we obtain :

$$\begin{cases} \underset{L,S,Res,D,DM,Repo,RF}{\text{MAX}} \left[r_L L + r_S S + r_{es} Res - r_D D - r_{DM} DM - (rRepo) - r_f RF - C\right]/\overline{FP} \\ L + S + Res - DM - D - Repo - RF = \overline{FP} \\ kL + k'\left[S - e'\left(\frac{S - Repo}{1 - h'}\right)\right] > \overline{FP} \\ Res - (g + \alpha_1)D + (e' + \gamma_1)S + \gamma_1 a_1 \mathrm{L} + \gamma_2 a_2\,\mathrm{L} - \alpha_3 u(1 - a_1 - a_2)\mathrm{L} - \alpha_2 Repo \geq 0 \\ Res - (g + 0.25\alpha_1)D + e'S - (0.25\alpha_2)Repo - \left(0.25\alpha_3 u(1 - a_1 - a_2)\right)L \geq 0 \\ \left(1 - a_1 - a_2\right)\mathrm{L} + \mu S + (u\eta_2)L_l - DM - \eta_1 D < \overline{FP} \\ IL + IS + IRes + (I\beta u)\left(1 - a_1 - a_2\right)\mathrm{L} < \overline{FP} \\ L \geq 0; S \geq 0;\ Res \geq 0;\ D \geq 0;\ MD \geq 0;\ Repo \geq 0;\ RF \geq 0; \end{cases}$$

Assigning numerical values to the various regulatory coefficients and interest rates, and setting C = 3250 + 12496 = 15746 (in million CFA francs), FP = 3105.23 billion CFA francs, we obtain the following program to be solved:

$$\begin{cases} \underset{L,S,Res,D,DM,Repo,RF}{\text{MAX}} \begin{bmatrix} 2{,}186.10^{-8}L + 1{,}449.10^{-8}S + 9{,}661.10^{-9}Res - 1.742.10^{-8}D - 1{,}90.10^{-8}DM \\ -1{,}61.10^{-9}Repo - 3{,}129.10^{-9}RF - 0.005 \end{bmatrix} \\ L + S + Res - DM - D - Repo - RF = 3105227 \\ 0{,}08L - 0{,}048S + 0{,}052Repo < 3105227 \\ 0{,}192L + S + Res - 0{,}07D - 0{,}8Repo \geq 0 \\ -0{,}00825L + 0{,}5S + Res - 0{,}0325D - 0{,}2Repo \geq 0 \\ 0{,}561L + 0{,}25S - 0{,}67D - DM < 3105227 \\ 0{,}03198L + 0{,}03S + 0{,}03Res < 3105227 \\ L \geq 0; S \geq 0;\ Res \geq 0;\ D \geq 0;\ MD \geq 0;\ Repo \geq 0;\ RF \geq 0; \end{cases}$$

Appendix A2

Assuming price makers banks and decreasing returns are some restrictions guaranteeing $Res > 0$, $D > 0;\ RF > 0$. We obtain the following final program:

$$\begin{cases} \underset{L,S,Res,D,DM,Repo,RF}{\text{MAX}} \left[\begin{matrix} 2{,}186.10^{-8}L + 1{,}449.10^{-8}S + 9{,}661.10^{-9}Res - 1.742.10^{-8}D - 1{,}90.10^{-8}DM \\ -1{,}61.10^{-9}Repo - 3{,}129.10^{-9}RF - 0.005 \end{matrix} \right] \\ \begin{matrix} L + S + Res - DM - D - Repo - RF = 3105227 \\ 0{,}08L - 0{,}048S + 0{,}052Repo < 3105227 \\ 0{,}192L + S + Res - 0{,}07D - 0{,}8Repo \geq 0 \\ -0{,}00825L + 0{,}5S + Res - 0{,}0325D - 0{,}2Repo \geq 0 \\ 0{,}561L + 0{,}25S - 0{,}67D - DM < 3105227 \\ 0{,}03198L + 0{,}03S + 0{,}03Res < 3105227 \\ L \geq 0; S \geq 0;\ Res > 0;\ D > 0;\ MD \geq 0;\ Repo \geq 0;\ RF > 0; \end{matrix} \end{cases}$$