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Working Paper

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GLO Discussion Paper, No. 576

Provided in Cooperation with:
Global Labor Organization (GLO)

Suggested Citation: Nguena, Christian-Lambert (2020) : How does Fintech Innovation Matter for Bank Fragility in SSA?, GLO Discussion Paper, No. 576, Global Labor Organization (GLO), Essen

This Version is available at:
https://hdl.handle.net/10419/219986

How does Fintech Innovation Matter for Bank Fragility in SSA? *(Working paper)*

Christian-Lambert Nguena[1][2][3]

Abstract

There is a momentous debate on the role played by financial technology (fintech) innovation in the fragility of the banking sector. Considering the importance of financial solidness, contradictory theoretical predictions and empirical evidence, the in-depth re-investigation of this relation is needed. Using data of 690 banks across 34 Sub Saharan African countries for the period 1999-2015 along with FGLS, GMM, Panel Threshold regression and PCA econometric method, this paper empirically examines the influence of fintech innovation on bank fragility. Mainly the destabilizing impact of fintech innovation is confirmed for our baseline investigation but later relativized with a stabilizing impact after a certain threshold. Moreover, the results highlight also that the macroeconomic environment is important in explaining bank fragility and suggested that public policy should take into account some specific destabilizing consequences on the banking system. Besides, the simultaneous hypothesis test of the innovation-fragility nexus conditional to some relevant variables reveals that financial openness does matter while investment, commercial openness and monetary policy do not. Lastly, the comparative analysis validates our heterogeneity hypothesis; countries with the high size banking sector, colonialized by France and members of monetary union performs better than the others in terms of bank solidness. These results indicate that suitable fintech innovation policy even between the same regions could be rather different. Financial instability appeared also to increase bank fragility. This paper contributes to the limited literature on fintech innovation at both the macro and micro levels in sub-Saharan Africa.

Keywords: Fintech innovation – Bank fragility – Threshold regression – Technology transformation – FGLS – GMM – PCA.

JEL classification: G21 G28 G15 O31 033.

Introduction

Efficiency and to some extend prudential indicators (such as net interest margins or interest rate spreads) evidence that banks in SSA (Sub-Saharan Africa) are performing less than banks in other developing regions of the world and that the service cost is higher. In particular, the spread between debit and credit interest rates is higher (for example, in 2011 and 2018 it was respectively 10.3% and 9.1% in SSA, compared to 8.2% and 4.7% in Europe); also, the general costs of the SSA financial system amounted to 5.5% of the total assets, compared to 1.6% in Europe. Nowadays, to this situation already debated in the literature, is added a set of recent changes, mutations and innovations in financial systems under the name of fintech innovation[4] with both macroeconomic and microeconomic consequences. Thus as it has been done

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[4] "Fintech innovation" or "financial technology innovation" is financial innovation essentially drived by technologies; the financial industry has a set of innovations that share a common link of being enabled by technology. As clearly explained by Schindler (2016), FinTech is getting so much more attention than "traditional" innovation when we consider the financial sector. In the rest of the document financial innovation means fintech innovation or financial technology innovation.

elsewhere[5], African policy-makers must take into account this new deal to steer the result in the right direction.

In SSA, fintech innovation is quickly metamorphosing the financial system, giving a pitch to new forms of activities/lending and opening up a version of shadow banking. This is equally true for Asian countries (Lai & Order, 2017). Focusing on a sample of 32 developed countries, Beck et al. (2016) concluded on a dark side of financial innovation by finding its negative impact on bank fragility. Observing figure 1 and 2 bellows of both financial innovation and bank fragility overall average trend for 34 SSA countries, it shows that while financial innovation increases over the years, bank fragility trend is alternating increasing instability and stability respectively before and after 2008, which correspond to the financial crises. This stylized fact is highlighting that the results of Beck et al. (2016) about an absolute dark side of financial innovation may be questionable if we consider the context of SSA.

Fig. 1: Fintech innovation evolution

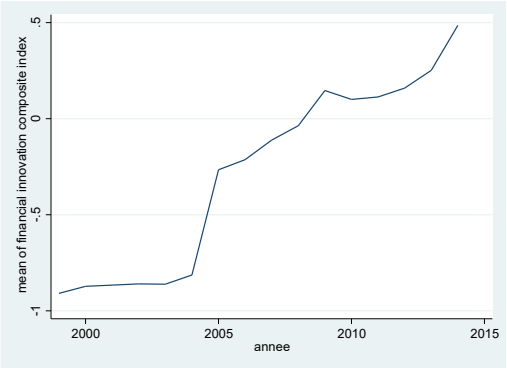
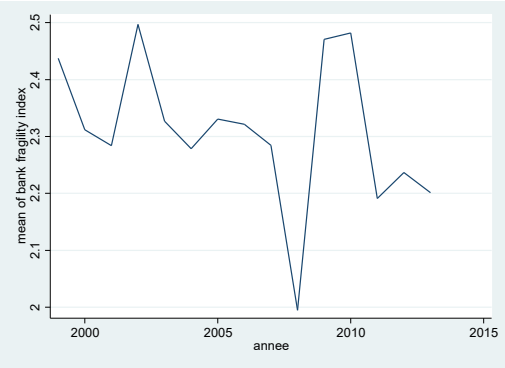


Fig. 2: Bank fragility evolution



Source: Author computation.
Notes: Overall trend of average fintech innovation (index constructed using Principal Component analyses) and bank fragility (Z-score) index for 34 SSA countries including South Africa - Benin - Burkina-Faso - Botswana - Burundi - Cameroon - Cape Verde – Ivory coast - Congo - Djibouti - Gabon – Gambia - Ghana - Guinea Bissau - Equatorial Guinea - Kenya - Madagascar - Malawi - Mali - Mauritania - Mauritius - Mozambique - Namibia - Nigeria – Central African Republic - Rwanda - Sao Tome & Principe - Senegal - Seychelles - Sierra Leona - Soudan - Swaziland - Chad and Togo.

High-income economies faced fintech innovation before low-income countries mainly constituted of the majority of SSA countries; while innovative assets offered by the banking sector were widely available and routinely used for consumer financing activities, many low and lower-middle-income countries were experiencing a beginning of fintech innovation impact with only a few numbers of such assets. Thus, what explains SSA bank fragility? Is SSA bank fragility just a symptom of fintech innovation? Or are there country/region factors and policies that specifically explain SSA bank fragility? Using macroeconomic data to document cross-country variation in bank fragility and explores country factors that can explain this variation for the specific case of SSA appear to be important.

The crisis in the international banking sector has come back to the forefront with the last mortgage crisis. Due to the enormous economic and social costs, it has generated unique characteristics in the economic history of the second half of the 20th century. However, given their recrudescence on a global and even African level since the end of the 1970s, the banking crises have a recurring character. Mainly due to the implementation of financial liberalization policies and the development of financial innovation, the financial system development seems to

[5] Beginning 2010, the Economist organized a debate between Ross Levine and Joseph Stiglitz on the role and benefits of financial innovation during 10 days.

be a factor in the banks' vulnerability. On the opposite, the increase in the size and activity of financial intermediaries will allow banks to gain in experience and limit their vulnerability and therefore their risk of crisis, thanks to better management information asymmetry on the credit market and improved ability to spread risk. This will ultimately lead to greater efficiency and less risk of credit allocation in the economy.

Consequently, the impact of fintech innovation on the degree of vulnerability of banks seems uncertain. Although empirical literature insists on financial factors to explain the vulnerability of the banking sector, it generally adopts a narrow vision of the concept of fintech innovation; in most cases, innovation in financial technology is only indexed by indicators associated with the level and rate of credit growth. Many factors are proposed in the literature to explain the banking crisis in SSA and the resulting vulnerability of banks. This work relies heavily on credit control measures by government authorities, poor banking management, inadequate monetary policy, an unfavourable macroeconomic context and weak links in the legal and regulatory framework (Caprio & Klingebiel, 1996; 2003 and Eboué, 2007). A contribution to this existing literature on the subject would, therefore, consist in taking into account the proposals for simultaneity of impact with financial opening, monetary policy, financial instability and trade opening.

Similarly, the importance of fintech innovation on growth largely within the literature (Romer, 1986; Lucas, 1988; Beck et al., 2016) and on the other hand the importance of banking stability/solidness due to the potential costs of bank fragility (Reinhart & Rogoff, 2009) are no longer to be demonstrated. This is particularly true for the SSA countries which have experienced several waves of banking crises turned into economic crises since independence. In such a context, mastering the relationship between fintech innovation and bank fragility is important.

That is why the objective of this paper is to analyze the impact of fintech innovation on bank fragility. This is envisaged from a broader and more precise perspective than those adopted in the econometric studies carried out so far on the subject; in particular, by carrying out a rigorous analysis of the different sources of bank fragility associated with fintech innovation and hence the level, growth and instability of the size and activity components of the banking sector on one hand, and the analysis of the possibility of a nonlinear relation with a threshold effect on the other hand.

We use a panel of 690 banks from 34 African countries over the period 1999-2014. In line with advanced estimation models of the macroeconomic determinants of the functioning of banking activities, our econometric modelling is based on the estimation of static, dynamic and threshold effect panel models with estimation methods. To rigorously assess the determinants of bank fragility in Africa, and based on a composite index of fintech innovation coming from the application of a Principal Component Analysis, our econometric analysis proceeds in four stages according to a logic going from general to particular.

This objective presents the following main importance and interest: Firstly in a context of the pandemic of COVID19 which is announcing a high recession or more, a depression, it is important to provide scientific-based answers on the fragility of the economic system and especially of the banking sector[6]. Secondly, bank failure is a potential channel through which

[6] A set of policy measures already taken by SSA countries and by type of measure in support of the financial sector to address the impact of the COVID-19 pandemic are available on the World Bank website. Restriction in the distribution of dividends for banks; framework to support companies affected; allocation to the subsidy funds …etc.

this health crisis could imply a great recession; the solidity of the banking sector is, therefore, important for a growing economy. Even before the last 2009 financial crisis, many studies warned that fintech innovation has a dark side (Beck et al., 2016); a 1% increase in bank fragility related to the US financial crisis of 1893 reduced state output growth between 1900 and 1930 by 2–5% (Ramírez, 2009). Finally, our analysis is of particular interest in terms of macroprudential policy implications, since it allows us to identify a very precise structure of exposure to the risk of financial intermediaries in the run-up to a banking crisis. This may be subject to increased surveillance by the public authorities, in particular concerning the implementation of preventive actions on the part of central banks.

The results we obtain confirm the relevance of our analysis method which consists of adopting not only fintech innovation and all satellite aspects to it for a broader and more precise analysis, but also a sequential approach with control of the heterogeneity and non-linear control with the estimation of the fintech innovation-bank fragility relationship threshold (s). In general, our estimates highlight the significant and negative impact of fintech innovation on bank fragility; moreover, we show that heterogeneity, simultaneity and non-linearity are valid to different degrees. This last result is linked to our motivation to go beyond the empirical analysis that Beck et al. (2016) did as a pioneer and long before us, by limiting themselves to the negative impact which he considered to be the dark side of financial innovation with a sample of 32 developed countries.

The rest of the paper is organized into six sections. Section 2 reviews the existing literature on the subject. Section 3 analyses some stylized facts and outline the theoretical framework. Section 4 presents our database, the econometric methodology used, as well as the strategy behind our estimates. Section 5 presents the discussion of the basic model results, followed by an extension with the consideration of the potential non-linear effects, of simultaneity and heterogeneity and finally of verification of the robustness. Section 6 concludes.

2. The effect of fintech innovation on banks fragility: *What does the existing literature tell us?*

To external observers, the rate of change in the financial sector is as impressive as its diversity. There is no doubt that this speed has a major impact on the fragility (or vulnerability) of the modern banking system, and its anti-deterioration capacity depends on its anti-shocks capacity (De Boissieu, 1987). Also, the analysis of financial innovations has been less thorough than that of industrial innovations to which they are moreover closely linked. However, due to a certain catch-up effect and an acceleration of the phenomenon since the mid-1970s, the economic analysis of financial innovation developed under the impetus of Silber (1975, 1983) and Kane (1981, 1984).

The theoretical literature is marked by a lively controversy on the consequences of the occurrence of innovation on bank fragility. Building from Duffie & Rahi (1995)[7] which provided a consistent theoretical literature review related to financial innovation. According to Khraisha & Arthur (2018), even if the theory of financial innovation has been a focus at a time of re-evaluation and re-conceptualization, little has been done to evaluate the current state of research given the increasing complexities in the financial innovation process; they built up initially that the complexities and diversities of financial innovation give rise to the infeasibility to build a

[7] They did a survey and presented general equilibrium models of financial innovation and provided a unified framework integrating impact studies of financial innovation on risk-sharing and information aggregation.

unifying general theory of its development; and that the present status of financial innovation examination is partial and necessitate supplementary contribution. Despite that, Beck et al. (2016) highlighted two main lines of research: The first is the traditional *innovation-growth*[8] view which posits that financial innovation reduces the fragility of banks while for the *innovation-fragility* view, financial innovation is positively related to bank fragility.

The *innovation-fragility* aspect centers on the dark face of financial innovation. Financial innovations like securitization change the ex-ante motivations of financial intermediaries towards carefully examine and scrutinize the borrowers (Allen & Carletti, 2006). Wagner (2007a, b) shows that financial innovations that moderate asymmetric information can intensify risk-taking due to agency issues among bank proprietors and directors, or because of the lower costs of fragility. In the framework of the latest lending boom and consequent global financial crisis, many authors have pointed to distortions introduced by financial innovations, such as securitization and new derivative securities, and how they have contributed to forceful risk-taking, drop in lending standards and hence fragility (Rajan, 2006; Dell'Ariccia et al., 2008; Keys et al., 2010; Gennaioli et al., 2012). Particularly, it recognizes financial innovations as the source of the later global financial crisis by driving to an exceptional credit expansion that contributed to the boom and following bust in housing prices (Brunnermeier, 2009), by designing securities perceived to be secure but exposed to neglected risks (Gennaioli et al., 2012), and by helping banks to expand structured products to exploit investors' misunderstandings of financial markets (Henderson & Pearson, 2011).

Based on this theoretical framework, several empirical works have been executed. Frame & White (2004, 2009) did a relative complete survey of the empirical literature; we intend then to focus more on recent literature after 2009. Then the main difference of these work was the sample, the empirical strategy along with. However, the empirical literature based on innovation-fragility is more recent and scarce mainly due to the relative lack of data. As a corollary, the majority of existing studies concentrate on extremely restricted innovations such as novel forms of financial securities (Grinblatt & Longstaff, 2000; Schroth, 2003; Henderson & Pearson, 2011), the introduction of credit scoring strategies (Frame & White, 2004, 2009; Akhavein et al., 2005), innovative forms of mortgage lending (Gerardi et al., 2010) or modern organizational forms like Internet-only banks (DeYoung, 2001, 2005; DeYoung et al., 2007). These studies so far have yielded mixed findings. The review of relevant works can be presented in the following two categories based on the quality of this impact.

2.1. The stabilizing effect of fintech innovation on the banking system

On the one hand, there is supporting evidence that financial innovation increases bank growth and supports financial deepening. For instance, Saretto & Tookes (2013) find that CDS[9] exchanging expand bank credit furniture, whereas Norden et al. (2014) demonstrate that banks that employ credit derivatives as a risk management instrument pass these benefits to their clients in the structure of lower interest spreads and reduce lending fewer during the latest crisis. Utilizing "counterfactual historic analysis", Lerner & Tufano (2011) document the positive

[8] The traditional *innovation-growth* view posits that financial innovation improves the quality and variety of banking services (Merton, 1992; Berger, 2003), facilitates risk sharing (Allen & Gale, 1988, 1991 and 1994), completes the market (Duffie & Rahi, 1995; Elul, 1995; Grinblatt & Longstaff, 2000), and improves allocative efficiency (Ross, 1976, Houston et al., 2010).

[9] CDS= Credit Default Swaps.

contribution to financial deepening and economic growth of financial innovations, such as venture capital and equity funds, shared and exchange-traded funds, and securitization.

2.2. The weakening effect of fintech innovation on the banking system

On the other hand, financial innovations such as securitization change the ex-ante motivations of financial intermediaries to carefully examine and monitor borrowers (Allen & Carletti, 2006). Within the environment of the recent lending boom and successive global financial crisis, many authors have pointed to distortions introduced by financial innovations such as securitization and new derivative securities, and how they have contributed to destructive risk-taking, the decline in lending standards and thus fragility (e.g., Keys et al., 2010; Gennaioli et al., 2012). Subrahmanyam et al. (2014) demonstrate that CDS trading significantly increases credit risk as financial institutions downgrade monitoring, while Wang & Xia (2014) document that banks make use of less effort on ex-post monitoring when they can securitize credits.

Beck et al. (2016) utilized a sample of 2000 banks over 32 developed countries during the period 1996-2010 and established that financial innovation is associated with bank fragility. Lai & Order (2017) provided a theoretical analysis of potentials risks impact of fintech finance on the financial sector in China; they point out that these risks are most probable to be substantial when fintech progress beyond its technological focus and performs financial intermediation, particularly bank-like, functions. They finally proposed a framework as an approach to mitigate risks from contagion linked to fintech innovation phenomenon.

At the end of this section, there is no conclusive evidence on whether financial innovation is virtuous or bad for the bank fragility. Additionally, apart from that of Beck et al. (2016), none of the existing papers has taken a holistic approach to financial innovation and its implications for bank fragility. However, Beck et al. (2016) did not question other aspects such as non-linearity. Thus, in the logic of the models of analysis of bank fragility and with an implicit target to built on the existing studies to contribute to the literature, the objective of our empirical analysis is to determine with accuracy the quality of the relationship between financial innovation and bank fragility along with the macroeconomic aspects that influence this relationship.

3. The effect of fintech innovation on banks fragility: *stylized facts and theoretical framework*

3.1. Ongoing movement within the SSA banking sector

After several consecutive years of decline, the majority of banks in Africa returned to growth in 2017. The aggregate balance sheet of the African banking sector grew strongly with an increase of 18.7%[10], the cumulative revenues experienced a sharp increase of 10 billion USD in 1 year and the profits made have crossed the 25 billion USD, which corresponds to the best performances of the last decade. This is the result of favourable[11] economic conditions in general and attractive exchange rates in particular. In 2017, the African banking sector is in the second position in the world ranking in terms of profitability. Just behind that of Latin America, its 15% return on investment was comparable to that of Asia and the Middle East.

[10] Rising to $ 1.8 trillion.

[11] Indeed, Nigeria is emerging from its first recession which has passed twenty years; Morocco, the continent's third largest banking center, returned to 4.1% growth, after a disappointing year in 2016; South Africa and Egypt recorded GDP increases of 1.3% and 4.2% respectively.

The fact that the good results observed in 2017 are much more correlated with a dispersed exit from the crisis than with a general movement affecting the entire banking industry, militates for the observation of regional divergences in the potential determinants of banking solidity. There is also a contrasting development of African currencies against the dollar[12]. Besides, the loan clearance started a few years ago is bearing fruits[13].

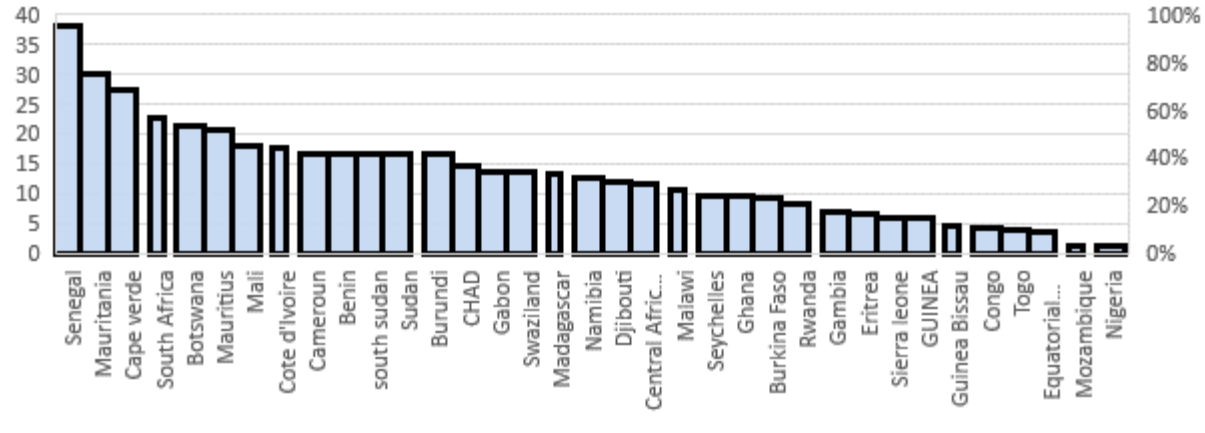
However, it is important to note that these performances are essentially characterized by regional divergences which were reinforced during the second half of the last decade. The domination of southern Africa is confirmed, with almost 51% of the cumulative balance; retaining 30.4% of assets, the North African banking sector driven by Morocco and Egypt ranks second; West Africa, pulled by Nigeria has a weak performance of 12.3% of the balance sheet. Central Africa, mired in an economic crisis for several years, falls below 1% of the total. Beyond these heterogeneities linked in turn to membership or not to a monetary union, membership of the same sub-region and the size of the banking sector, there are several other reasons why we cannot, however, conclude that the years of bank fragility are behind the banking sectors of SSA.

Indeed, the banking weaknesses that have appeared in recent years persist in particular in SSA. SSA banking markets are still struggling to improve the supply of credit. Several African banks remain vulnerable to the new capital requirements, following the gradual implementation of the Bale II and Bale III agreements. Recently, the Central Bank of Ghana nationalized two banking institutions, withdrew licenses from 70 microfinance institutions, and tripled the minimum capital required. Likewise; the recapitalization needs in Ghana exceed 1.4 billion USD. These weaknesses are likely to be reinforced by the implementation of new standards and to some extent by the advent of financial innovation.

3.2. Fintech innovation and bank fragility across countries

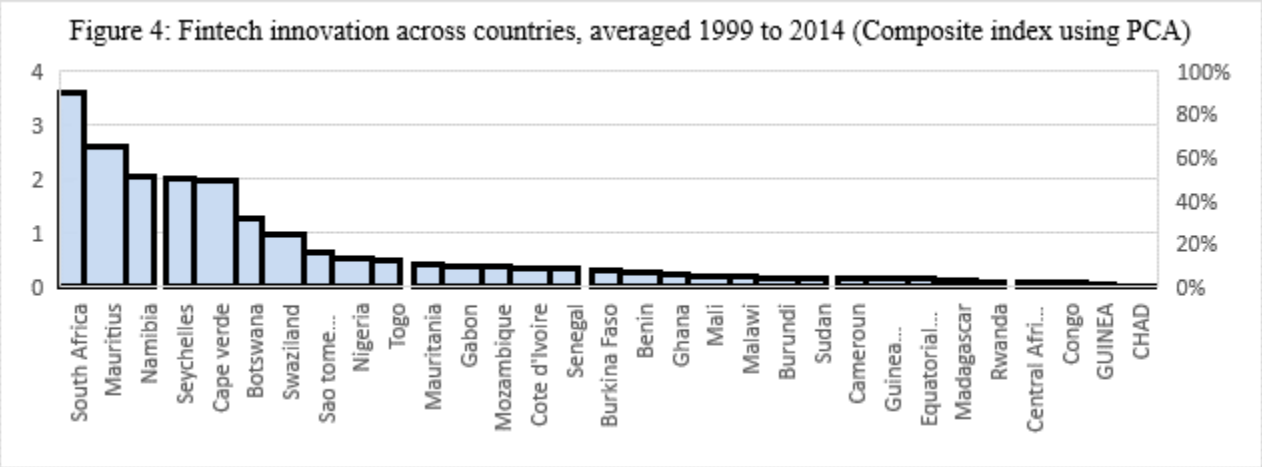
Figures 3 and 4 bellow portrays classification in terms of bank fragility and fintech innovation averaged 1999-2014 performances among SSA countries.

Figure 3: Bank fragility across countries, averaged 1999 to 2014 (zscore)



[12] The Nigerian naira remained relatively stable against the USD; the Egyptian pound resisted after losing half of its value during the 2016 devaluation; the South African rand gained more than 11% against the USD, boosting the banks' relative resilience.

[13] As shown for example, by the reduction in provisions for bad debts of the Ecobank banking group, with an increase in profit which rose to 229 million USD in 2017 after a loss of 205 million USD in 2016.



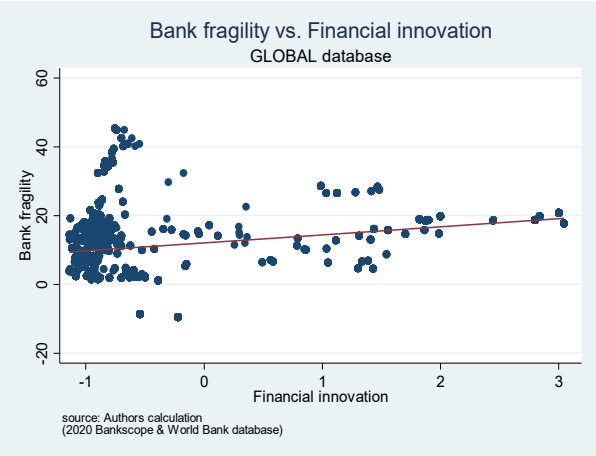
Source: Author construction. PCA=Principal Component Analysis; SSA=Sub Saharan African countries.

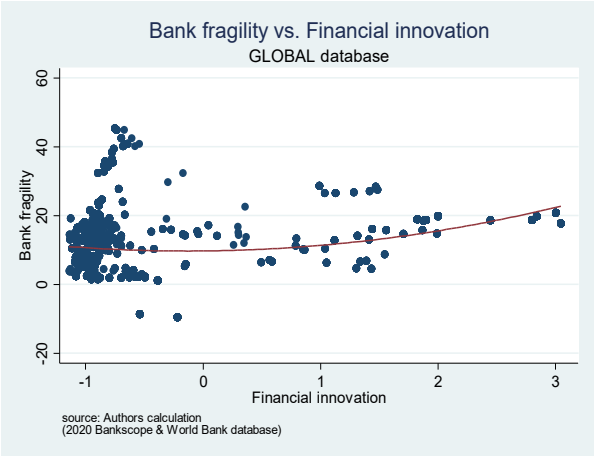
The observation of these figures above tells us that the performances are disparate across all sub-regions. On the one hand, some countries have the characteristic of high levels of bank fragility coexisting with high levels of financial innovation. South Africa has the strongest performance in terms of the degree of financial innovation with a relatively high level of fragility. Nigeria for West Africa also has a much lower level of bank fragility than its degree of financial innovation. On the other hand, some countries highlight the opposite situation. Cameroon, for example, presents a contrast with a level of fragility much higher than its degree of financial innovation; Senegal, Mauritania, Mali, Chad, Benin, Madagascar, Rwanda, the Central African Republic, Sudan, Equatorial Guinea to name but a few also have the same characteristic.

In the same vein, the graphs of bank fragility and fintech innovation index per country in annexe clearly show that there are a low level and almost a stability at a low level or a growth a decreasing rate which means high fragility and coexisting with a relatively stable and increasing level of fintech innovation.

In addition to these statistical findings, the figures 5 bellows show that the correlation between both main variables can be linear or nonlinear.

Figure 5: Bank fragility versus fintech innovation in SSA



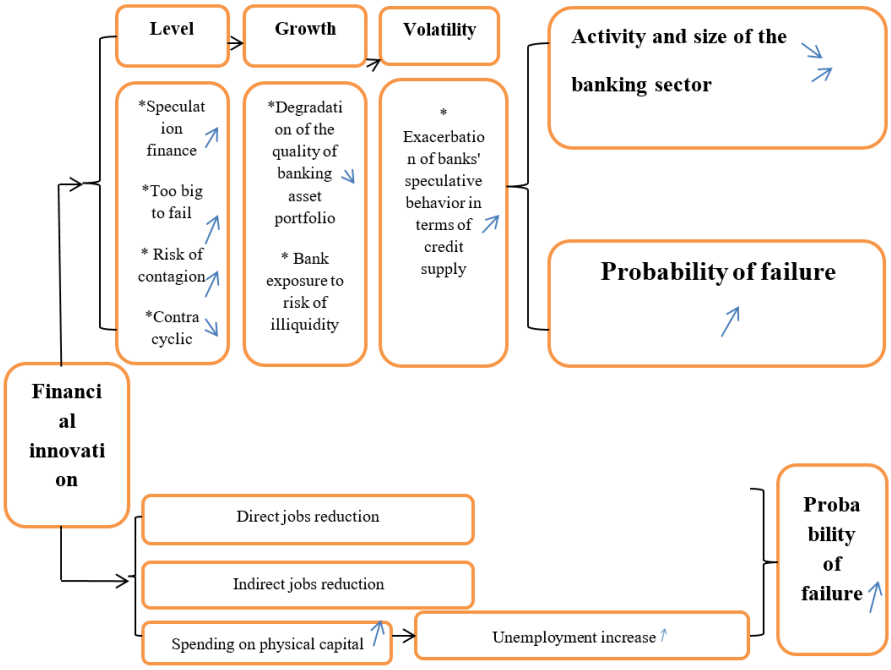


The figures A4 in appendix firstly reinforce this last affirmation with the same conclusion while grouping countries and secondly show that we have different potential relation between our two main variables. It is important to conceptualize the theoretical framework in light of the previous literature review and stylized fact presentation.

3.3. The theoretical framework

The figure 6 below summarizes the different channels through which fintech innovation, viewed from the perspective of the level, growth rate, volatility and employment of the size and activity of the banking sector, can increase the probability of occurrence of banking failure.

Figure 6: Theoretical linkages between fintech innovation and bank fragility.



Source: Authors construction.

However, the statistical findings presented above allow us to put this theoretical model into perspective by justifying and opening the way to a confrontation with empirics.

4. The effect of fintech innovation on banks fragility: *Empirical design*

This section presents the tools and conditions to ensure a robust empirical investigation. It consists of the presentation of the data source and manipulation method, the model specification based on the theoretical framework presented above along with the estimation strategy and the presentation of the variables.

4.1. Database description

This study uses annual data and draws on a sample of 690 banks from 34 countries in sub-Saharan Africa over the period 1999-2014. As it is common in most empirical macro-econometric analysis, we used two-dimensional data: a chronological dimension and a spatial dimension. Bank-specific data are obtained from the *Bankscope* database. The macroeconomic data are derived from the WDI (world development indicator) database. The Chinn-Ito index of

financial liberalization has an average of 0 and a spread of -2,66 representing a complete liberalization. Higher values of financial openness indicate the index of a country that is more open to cross-border capital dealings. The indicator is calculated yearly and is accessible from 1970 to 2014. Additional information on the construction of the Chinn-Ito index is presented in Chinn & Ito (2008). Accordingly, in addition to these data extracted from these databases, dummies, composed (financial instability and other variables) and constructed variables (fintech innovation index) were also considered.

We introduced dummies to capture the effect of the banking sector size, of the membership of a monetary union (having signed an agreement of monetary union or not) and of the colonialism language heritage (either French or English for this case mainly because it is the main language from colonialisms; other languages such as Spanish and Italian are marginal). The idea behind the introduction of these dummies is strongly related to the theory presented above. Firstly, the size of the banking sector comparative to the dimension of the whole economy might have a connection with the solidness of the banking sector; following Oduor & Kebba (2019), the size of the banking sector is indexed with the ratio of domestic credit provided by the banking sector to GDP. Large banking sector economies are countries with this ratio above 100%, while medium and small-sized banking sector economies are characterized respectively with this ratio between 50% and 100% and less than 50%. Secondly, we assume that the health of the banking system depends on the monetary management environment. For example, the way monetary policy is implemented in a monetary union is not the same is we consider a single country; this aspect is non-negligible since monetary policy can affect the banking activity and thus the stability of the sector. Finally, the colonialism origin can affect the banking sector activity through its impact on the institution behaviours; many studies agree that most of African countries policies are linked to the one of their colonizers (Moradi, 2009; Gareth, 2010).

Additionally and consistent with the existing literature, financial instability index has been built from price stability index volatility captured by the relative standard deviation. Practically, the financial instability index is computed with the variance operator to capture the volatility of inflation rate. 4 other composed variables have been constructed to permit the test of simultaneity hypotheses with fintech innovation index of financial openness, inflation rate, trade openness and investment.

Finally, we used the principal component analysis to construct our variable of fintech innovation. The table A7 in annex present a more detailed database with description, source and abbreviation. List of countries, correlations along with statistics description are also available in the tables A1, A9, A10, A11 and A13.

4.2. Econometric modelling approach and estimation strategy

Models examining the influence of fintech innovation and other macroeconomic variables on the probability of bank failure are numerous (Beck et al., 2012; Laeven & Levine, 2012 and Houston et al., 2012); however, the one that is better adapted for our case is inspired by the works of Beck et al. (2016) who modelled the relationship based on a literature review and highlighted the following function:

$$FintechInnov = f(Financial\ policies, Physical\ capital, Human\ capital) \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Based on this functional relation, we propose to estimate a model in which the variable explained is the risk of bank failure and the explanatory variables fintech innovation and all the relevant variables identified in the theoretical and econometric literature.

As stated in the introduction, we intend to analyze all potential possibilities of the impact including simultaneous hypothesis test, non-linearity, threshold regression among others. First, the relationships between fintech innovation and bank fragility will be tested and then this relationship will be tested by integrating control variables.

Our baseline model derived from the above functional relation is specified as follows:

$$BF_{i,k,t} = \theta + \gamma FI_{i,t-1} + \alpha BC_{k,t-1} + \beta CC_{i,t-1} + \nu_i + \sigma_t + \varepsilon_{i,k,t} \quad \text{..... (1)}$$

For the deterministic part of the equation, *BF* is the Z-score of the bank *k* in the country *i* at date *t*; *FI* is the indicator of the level of fintech innovation of countries; *BC* is the vector of the characteristics of the banks; *CC* is the vector of country characteristics; θ is the constant vector and γ, α, β the parameters vectors. $\nu_i + \sigma_t + \varepsilon_{i,k,t}$ represent the stochastic part of the equation with the error terms. For both deterministic and stochastic part, the indices *i, k,* and *t* represent respectively the countries, the bank and the time respectively.

The methodology of the estimation of the potential non-linearity consist of the following two steps:

✓ Firstly, the model to be estimated is the baseline presented above and augmented with the squared values of our main independent variable as follow:

$$BF_{i,k,t} = \theta + \gamma_1 FI_{i,t-1} + \gamma_2 FI_{i,t-1}^2 + \alpha BC_{k,t-1} + \beta CC_{i,t-1} + \nu_i + \sigma_t + \varepsilon_{i,k,t} \quad \text{..... (2)}$$

✓ Secondly, in case of a conclusive test of the non-linearity in general and the existence of a U-relationship in particular, we intend to go beyond and estimate the threshold using the panel threshold regression methodology. Threshold regression models are a diverse set of non-regular regression models that all rely on change points or thresholds. To allow for contrasting/different effects of fintech innovation on bank fragility in the "low- fintech innovation" and "high- fintech innovation" regime respectively, we can upon implement a threshold regression (Hansen, 2000). We have the following specifications either for the case of a single-threshold model (3) or for the case of a multiple-thresholds model (4):

$$BF_{i,k,t} = \begin{cases} \theta_{10} + \gamma_{11} FI_{i,t-1} + \cdots + \nu_i + \sigma_t + \varepsilon_{i,k,t}, & if\ FI_{i,t-1} < \vartheta \\ \theta_{20} + \gamma_{21} FI_{i,t-1} + \cdots + \nu_i + \sigma_t + \varepsilon_{i,k,t}, & if\ FI_{i,t-1} \geq \vartheta \end{cases} \quad \text{..... (3)}$$

Where, $FI_{i,t-1}$ is the threshold variable separating all the observations into two groups; and γ_{11}, the threshold value to be evaluated using the least-squares method.

$$BF_{i,k,t} = \begin{cases} \theta_{10} + \gamma_{11} FI_{i,t-1} + \cdots + \nu_i + \sigma_t + \varepsilon_{i,k,t}, & if\ FI_{i,t-1} < \vartheta_1 \\ \theta_{20} + \gamma_{21} FI_{i,t-1} + \cdots + \nu_i + \sigma_t + \varepsilon_{i,k,t}, & if\ \theta_1 \leq FI_{i,t-1} < \vartheta_2 \\ \theta_{30} + \gamma_{31} FI_{i,t-1} + \cdots + \nu_i + \sigma_t + \varepsilon_{i,k,t}, & if\ FI_{i,t-1} \geq \vartheta_2 \end{cases} \quad \text{.....}$$

(4)

Besides, as announced, we will implement other specific estimation by joining the baseline model some relevant specific characteristics related to the potential heterogeneity of our sample.

The introduction of dummies will allow us to carry out a comparative econometric study between French-speaking Sub-Saharan African countries and other countries; between countries belonging to a monetary union and non-monetary union countries and between countries with small, medium and large size of the banking sector. As the equation (5) bellow is showing, we will consider the following dummies: the size of the banking sector (*BS*), the colonizer origin (*CO*) and the monetary union membership (*MU*).

$$BF_{i,k,t} = \theta + \gamma FI_{i,t-1} + \partial_1 BS_{i,t-1} + \partial_2 CO_{i,t-1} + \partial_3 MU_{i,t-1} + \alpha BC_{k,t-1} + \beta CC_{i,t-1} + \nu_i + \sigma_t + \varepsilon_{i,k,t} \quad \text{.........(5)}$$

Likewise finally, we took into account the potential variform of the effect of fintech innovation on the degree of bank fragility mentioned in the introduction, with the implementation of tests of simultaneity hypotheses. Although the empirical literature insists on the central role of financial factors in explaining bank fragility, it often takes a very narrow view of the concept of fintech innovation, since most of the time it is considered only through indicators relating to the level and/or rates of growth of credit. The whole problem with such an approach is that in this case, it is not possible to highlight what are the precise components associated with fintech innovation which significantly and robustly affects the level of bank fragility. Practically, we will use the augmented model (6) bellow to perform the test of the following simultaneity hypothesis test of fintech innovation with respective investment (*FIxIV*), commercial openness (*FIxTO*), financial openness[14] (*FIxFO*) and monetary policy[15] (*FIxMP*):

$$BF_{i,k,t} = \theta + \pi_1 (FI * IV)_{i,t-1} + \pi_2 (FI * TO)_{i,t-1} + \pi_3 (FI * FO)_{i,t-1} + \pi_4 (FI * MP)_{i,t-1} + \alpha BC_{k,t-1} + \beta CC_{i,t-1} + \nu_i + \sigma_t + \varepsilon_{i,k,t} \quad \text{..........(6)}$$

Beyond its level and its growth rate, the instability of the financial intermediation system environment would constitute one of the major causes explaining banks fragility. An unstable environment supposes, for example, that during the ascending phase of the financial cycle, we will have an exacerbation of the speculative behaviour of banks, reinforcing the risks which in the end will most likely lead to an increase in the degree of banks fragility. This dimension is too often neglected in the empirical literature on the determinants of banks fragility. Thus, for robustness check, we will verify if the financial stability (*INS*) matter using the following specification constructed from the baseline equation:

$$BF_{i,k,t} = \theta + \gamma FI_{i,t-1} + \varphi INS_{i,t-1} + \alpha BC_{k,t-1} + \beta CC_{i,t-1} + \nu_i + \sigma_t + \varepsilon_{i,k,t} \quad \text{..........(7)}$$

The Feasible Generalized Least Squared method (FGLS)[16] for static specification and Generalized Method of Moments (both first difference and system GMM) for dynamic specification will be applied on models (1), (2), (5), (6) and (7) while Panel Threshold Regression method will be employed for the models (3) and (4) to estimate the threshold. The powerfulness of these methods relative to others has been substantially demonstrated within the

[14] Considering the effect that financial openness could exert, a factor which nonetheless underlies the dynamics causing bank fragility.
[15] It takes into account the liquidity risk faced by banks during the upward phase of the financial cycle to explain bank fragility.
[16] Given that structure of our database and in order to correct autocorrelation and heteroscedasticity potential problems we choose FGLS with robust standard errors instead of OLS with panel-corrected standard errors (PCSE) and simple fixed-effects regression.

hold and recent literature (Arelano & Bond, 1991; Roodman, 2009; Wang, 2015). The standard errors of the estimated parameters are corrected using the standard Windmeijer (2005) finite sample procedure.

4.3. Variables specification and construction

We present here firstly the main variable of interest followed by the construction of the fintech innovation index, a set of variables commonly used in the literature are introduced into the model used to control the impact of characteristics other than fintech innovations, which may influence the risk of failure.

4.3.1. Dependent variable

As a measure of the risk of bank failure, we retain the approach proposed by Roy (1952), Blair & Haggestad (1978), Boyd & Graham (1988) and Goyeau & Tarazi (1992). They define the bankruptcy risk of a bank as the likelihood of its losses becoming greater than its funds. And they show that this probability is equal to:

$$BF = Z\text{-}score = \frac{MeanROA}{SdROA} + \frac{MeanROA\,(\frac{Bank\ Equity}{Assets})}{SdROA} \quad \text{(8)}$$

With the *ROA* (return on asset) as the asset profitability, and *SdROA* the standard deviation of *ROA* calculated by moving averages over six periods. An increase in Z-score reflects a decrease in the probability of bank failure; this measure bank's distance from insolvency (Roy, 1952). Consistent with Laeven & Levine (2009), Houston et al. (2010) and Beck et al. (2016), we use the logarithm of this last indicator as the bank fragility index; for robustness, we will repeat our estimation with *ROAE* (return on average equity) as an additional proxy of bank fragility.

4.3.2. Construction of the financial technology innovation index using Principal Component Analysis:

Defining financial innovation is quite complex. However, there have been several attempts at definitions starting with the concept of economic innovation. Through the history of innovation dating back to Schumpeter (1935), this concept became very popular in the 20^{th} century; however, few studies have critically examined works on innovation. Even though anthropologists, sociologists, historians and economists have initiated theories on technological innovation each in their respective disciplinary framework, however, the economic aspect remained dominant. Financial innovation remains a very ambiguous economic concept; which probably explains the multiplicity of definitions adopted in the literature. One of the most frequently used definitions of financial innovation is that proposed by Frame and White (2004), which considers it as "something new that reduces costs, risks or provides a product, service or instrument that responds to the requirements of the participants". Thus in this study, fintech innovation takes into account the part of financial development guided by technical progress; indeed, there is consistent empirical evidence that technological progress, national innovative capacity and the productivity gains are associated with innovation (Geroski, 1989; Färe et al.,1994; Fagerberg et al., 2007).

Existing literature used several proxies to index fintech innovation. This situation is mainly because there is no consensual measure of fintech innovation. We intend to go beyond this by constructing an index closer to SSA realities of the financial sector movements. In SSA, Fintech

is evolving speedily within the financial system, giving birth to new forms of credits and opening a version of shadow banking. The introduction of new financial instruments, intended for savers, considerably diversifies the menu of available financial assets.

Confirming Minsky's analysis of financial crises, the more recent fintech innovations may mainly be due to the traditional search of financial institutions to circumvent the post-crisis regulatory changes[17]. However, as Schumpeter's industrial innovations, recent fintech innovations in SSA are more likely to be directly linked to technological advances that have been shaping the economy in general, and the financial system specifically. The relative disconnection of the financial system of most SSA countries may have reduced the possibility of the first explanation in the profit of the second. Thus the closest aspect of financial innovation is the one related to technology development and called fintech innovation.

Thus, by considering fintech innovation, we deviate from the method used by Beck (2016) which were focusing on financial innovation which include the traditional aspect and the modern aspect based on technology development. Ils ont utilisé les données sur les dépenses recherche et développement (R&D) dans le secteur bancaire fréquemment utilisées pour mesurer l'innovation financière. Cependant, d'une part ces données publiées par the Analytic Business Enterprise Research and Development database (ANBERD) ne sont pas disponibles pour la plupart des pays Africains ; et d'autre part, their survey-based nature make them suceptible to potential measurement errors. Ce qui nous contraint tout en justifiant notre utilisation de la version moderne de l'innovation financière. Consistent with this, we applied principal component analysis method to the following proxies related to the modern part of financial innovation: Automated Teller Machines (ATMS); commercial bank branches (CONBANK); domestic credit to private sector by banks (DCPS); insurance Company Assets (ICS).

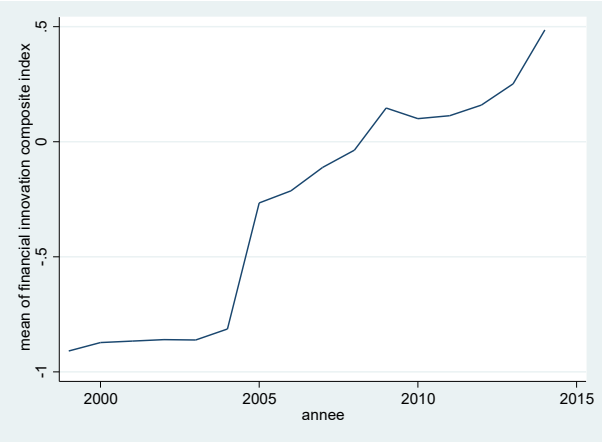
The descriptive statistics, correlations and multidimensional data analysis graphs related to the construction of this index are available in the annexe (Table A1, A2, A3 and A4; figures A1 and A2). As shown in the correlation matrix in table A3 in the appendix, the potentially high degree of substitutability between the different fintech innovation proxies implies that certain information could be redundant and / or missing if we choose only one of them. Indeed, these proxies are correlated with each other with correlation coefficients of at least 0.43. The composite index is itself strongly correlated (coefficients of at least 0.63) to its components, which corroborates with the assumption of a good synthesis of the information within the latter.

Without going into the details of the construction technique[18], as shown in Table A5 in the appendix, the results are reported. The criteria applied to determine the number of common factors to be used are taken from Kaiser (1974) and Jolliffe (2002). Kaiser recommends dropping factors with an eigenvalue of less than one. Figure 7 bellow portrays the evolution of fintech innovation index in SSA countries over the period 1999 –2015. Remarkably, the curve has the same shape and the same trend as that of the much more general index of financial innovation developed by Beck et al. (2016) for OECD countries.

[17] For exemple, as they did previous to the 2008 global collapse, banks and other financial institutions in USA have been leading the regulatory arbitrage dynamic fostered, mainly, by circumventing two new rules: restrictions on bank trading imposed by the 2010 Dodd-Frank Act, including the ban on banks' proprietary trading (Volcker rule 1); and increased capital requirements(Collins amendment 2), also enclosed in Basel III.

[18] Fintech innovation is a phenomenon for which variables defining it directly are almost absent in the literature. Consequently, the principal component analysis (PCA) is used to reduce the redundancy / absence of common information for the variable concerned and to contribute to the literature by highlighting a new index

Figure 7: fintech innovation index evolution



Source: Author computation.
Notes: Overall trend of average fintech innovation and bank fragility index for 34 SSA countries including South Africa - Benin - Burkina-Faso - Botswana - Burundi - Cameroon - Cape Verde – Ivory coast - Congo - Djibouti - Gabon – Gambia - Ghana - Guinea Bissau - Equatorial Guinea - Kenya - Madagascar - Malawi - Mali - Mauritania - Mauritius - Mozambique - Namibia - Nigeria – Central African Republic - Rwanda - Sao Tome & Principe - Senegal - Seychelles - Sierra Leona - Soudan - Swaziland - Chad and Togo.

4.3.3. Explanatory variables

Based on the empirical literature review and as Beck et al. (2005) and Jones & Krause (2007) did, the bank-specific variables are Life insurance premium volume / GDP; liquid assets; Net Interest Margin; Net Loans / Total Assets. Among them, we include the following control and dummies variables: GDP growth rate; inflation[19] ; Investment; education; population growth; commercial openness; financial openness; Bank size, Colonial language and monetary union membership dummies.

5. Fintech innovation and banks fragility: *Results discussion*

5.1. Fintech innovation and banks fragility: *What does the baseline estimation results tell us?*

Our main object of interest is not only testing for the presence of threshold effects but ultimately the estimation of the long-run effects of a persistent increase in fintech innovation on bank fragility, regardless of whether there is a threshold effect. In this section, we present the result of the baseline estimation. Our baseline estimation consists to verify the impact of fintech innovation on bank fragility, changing methods and conducting some econometric tests.

Table 1 above shows that our index of fintech innovation presents a negative and significant at 1% impact on bank fragility. This significant negative impact remains while we change estimation methods and model specification. Specifically, a one standard deviation increase in fintech innovation leads to an increase of bank fragility by 0.11 percentage point. The main implication of this negative impact is that fintech innovation as it is, cannot help for bank

[19] If the acceleration of inflation in the 1970s, through the rise in nominal interest rates and in fact the opportunity cost of unpaid balances, created a demand for new liquid and profitable financial instruments, the disinflation has not been symmetrically accompanied by a marked slowdown in the process of financial innovation. Empirical studies indicate that banks are more vulnerable to disinflation.

solidness. This result is understandable because fintech innovation at an early stage as it is common in SSA, means the implementation of new attitude, activities, using new tools to solve financial issues. So those new tools should be understood by every bank and percept so there may be a certain period for a bank to catch up in fintech innovation and during this period, fintech innovation is negative and at the basis of fragility in the banking sector. The results of research from many other authors attest this. Furthermore, analyzing the table A12 in the annexe, we found that the results of Gabon and Togo with the highest global significant[20] are negative and thus convergent to the estimation of our baseline model. Nevertheless, at this stage and to conclude on an absolute negative impact, we may deserve further analysis in the next sections.

For other bank-related variables such as life insurance, we have a positive impact so when implementing insurance activity development, we can be sure to contribute to the reduction in bank fragility; also for economic environment-related variables, only the human capital present a stabilizing impact. However, unemployment, inflation rate, financial openness, investment, commercial openness, GDP growth and population growth present negative and thus a destabilizing impact on bank fragility. Unemployment is at the basis of lower business since economic agents do not have the means to interact with banks and consequently a destabilizing impact on the banking system. Inflation leads to a higher bank fragility because it is linked to a higher economic activity but low viability of certain enterprises (Colomris, 1995). The monetary policy meant for fighting inflation is therefore valid by this result. Also, the results of Jones & Krause (2007) is confirmed with a destabilizing impact of GDP growth; indeed, GDP growth is correlated to a high level of economic activity and exposure, and thus could be linked to a high bank fragility.

However, from this last result, the cases of investment, commercial openness, financial openness and population growth are questionable regarding the theory. Investment indexed here by the cos fixed capital formation, also explain the fragility of the banking system. This investment is related to the high rate of economic activity which makes the banking system to have high potential exposure and fragility; this is the same situation with commercial openness and financial openness as well as population growth. Overall, and consistent to Colomris (1995), Demirguç-Kunt & Detragiache (1998) and Jones & Krause (2007), the macroeconomic environment is important in explaining bank fragility; these results suggest that government interventions can be destabilizing or destabilizing and that public policy should take into account the previous destabilizing consequences of its policy on the banking system.

Table 1: Impact of fintech innovation on bank fragility: Baseline estimations

	(1) OLS	(2) FGLS	(3) GMM
L.lnzscore			1.017***
			(0.00871)
Fintech innovation	-0.161***	-0.161***	-0.147***
	(0.0290)	(0.0289)	(0.0122)
Life insurance / GDP	0.0784***	0.0784***	0.0134***
	(0.00694)	(0.00693)	(0.00305)
GDP growth	-0.0513***	-0.0513***	-0.00807***
	(0.00496)	(0.00495)	(0.00219)

[20] The more R squared is higher, the more the model is adjusted to our data.

Inflation rate	-0.0211***	-0.0211***	-0.00186*
	(0.00280)	(0.00280)	(0.00113)
Unemployment rate	-0.0201***	-0.0201***	0.0113***
	(0.00249)	(0.00248)	(0.00112)
Financial openness	-7.5e-15***	-7.5e-15***	-2.4e-15***
	(7.6e-16)	(7.6e-16)	(3.4e-16)
Investment / GDP	-0.00484***	-0.00484***	0.00190***
	(0.000689)	(0.000687)	(0.000299)
Commercial openness	-0.330***	-0.330***	-0.00398
	(0.0279)	(0.0278)	(0.0116)
Population growth	-0.270***	-0.270***	-0.0717***
	(0.0239)	(0.0238)	(0.00902)
Human capital	1.469***	1.469***	0.443***
	(0.136)	(0.136)	(0.0603)
Constant	3.809***	3.809***	
	(0.150)	(0.150)	
Observations	2,793	2,793	2,780
R-squared	0.515	-	-
Number of ids	-	481	481
AR(2) test	-	-	0.192
Hansen OID test	-	-	0.944

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

Considering the explanation of the results presented above and also as explained in the introduction, we intend to foster our contribution to the existing literature by carrying out respectively the following additional empirical investigations: non-linearity test, Simultaneity test, heterogeneity test and robustness check with mainly the analysis of the impact of financial stability index. The following results can be read in two main ways. On the one hand, we assess whether the findings of the different impacts of fintech innovation on bank fragility are robust to the inclusion of non-linearities. On the other hand, we also explore whether a non-linear impact remains valid after controlling simultaneity or heterogeneity hypotheses.

5.2. Fintech innovation on banks fragility: *Is there always a bank fragility Kuznets curve?*

5.2.1. Test of non-linearity hypotheses:

Based on our statistical analysis which highlighted a quadratic fit, we assumed a potential U-shaped relationship. Table 2 below confirm the nonlinear relation hypothesis. Specifically, there is evidence of either a U curve (equation 5) or a cubic curve (equation 6) relationship between the two main variables of interest. This means that there are one or two certain thresholds respectively correlated to two or three regimes at which the negative relation between fintech innovation and bank fragility turns positive and vice versa. This statistically strong result is also economically strong. There is a negative relation followed by a positive relationship after reaching a threshold. One explanation is that innovation can contribute to banking solidness only after a certain delay. An innovation in its first moments can be considered as a shock for the economy in the sense that it must take time to understand and apprehend it; once this stage is closely correlated with time, one can begin to consume the fruit of the innovation in question; this explains even fits more with technological innovation. This result allows us to affirm that the

conclusion of Beck et al. (2016) of an absolute destabilizing impact of financial innovation on the banking sector should be relativized.

Table 2: Impact of fintech innovation on bank fragility: Test of non-linearity hypotheses

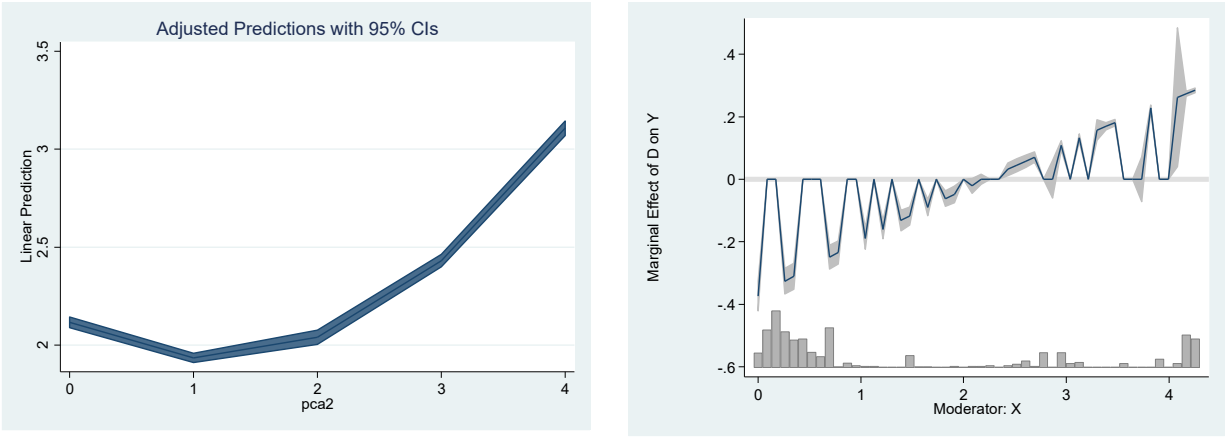
	(1) OLS	(2) OLS	(3) FGLS	(4) GMM 1st dif.	(5) GMM Syst.	(6) GMM Syst.
L.lnzscore				0.298***	1.044***	1.031***
				(0.0254)	(0.00942)	(0.00948)
Fintech innovation	-0.579***	-1.809***	-1.809***	-3.304***	-0.402***	0.0183
	(0.0775)	(0.136)	(0.136)	(0.0661)	(0.0355)	(0.0626)
Fintech innovation squared	0.105***	0.177***	0.177***	0.305***	0.0301***	-0.145***
	(0.00992)	(0.0144)	(0.0143)	(0.00679)	(0.00392)	(0.0218)
Fintech innovation cubic	-	-	-	-	-	0.0174***
						(0.00213)
Life insurance / GDP		0.118***	0.118***	-0.0445***	0.0171***	0.0357***
		(0.00748)	(0.00746)	(0.00582)	(0.00309)	(0.00383)
GDP growth		-0.0459***	-0.0459***	-0.0225***	0.000601	-0.00194
		(0.00485)	(0.00484)	(0.00207)	(0.00246)	(0.00247)
Inflation rate		-0.0233***	-0.0233***	-0.0138***	0.00121	-0.00101
		(0.00273)	(0.00273)	(0.00110)	(0.00120)	(0.00122)
Unemployment rate		-0.0175***	-0.0175***	-0.0860***	0.0108***	0.0117***
		(0.00243)	(0.00243)	(0.00977)	(0.00112)	(0.00112)
Financial openness		-8.8e-15***	-8.8e-15***	-0.0160***	-2.3e-15***	-2.6e-15***
		(7.5e-16)	(7.5e-16)	(0.00167)	(3.4e-16)	(3.4e-16)
Investment / GDP		-0.00601***	-0.00601***	0.00347***	0.00211***	0.00139***
		(0.000677)	(0.000676)	(0.000258)	(0.000300)	(0.000311)
Commercial openness		-0.0777**	-0.0777**	-0.120**	0.0691***	0.123***
		(0.0340)	(0.0339)	(0.0547)	(0.0150)	(0.0163)
Population growth		-0.587***	-0.587***	0.477***	-0.0907***	-0.200***
		(0.0346)	(0.0345)	(0.0652)	(0.00937)	(0.0163)
Human capital		1.342***	1.342***	-0.0307	0.494***	0.343***
		(0.133)	(0.132)	(0.132)	(0.0608)	(0.0631)
Constant	2.871***	6.520***	6.520***	-	-	-
	(0.128)	(0.264)	(0.263)			
Observations	5,136	2,793	2,793	2,236	2,780	2,780
R-squared	0.158	0.540	-	-	-	-
Number of id	-	-	481	416	481	481
AR(2) test	-	-	-	0.690	0.890	0.723
Hansen OID test	-	-	-	0.525	0.530	0.301

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

Considering the control variables, we have the same impact but for unemployment, we can have both positive and negative impacts which can mitigate our preceding conclusion. Hence, we cannot attest unemployment to have either a positive or a negative impact. Since this is not the focus of our analysis we can move to other impacts. For commercial openness also we may sometimes have positive as well as negative impacts, the same situation is also seen when population growth and education are considered. In the end, the existence of nonlinearity between fintech innovation and bank fragility is more explicit in the following explanation.

For further analysis and diagnostic purposes, we implemented post estimations investigation to capture the evolution of the marginal impact of fintech innovation on bank fragility. The results are presented in figures 8 bellows. The first graph confirms the hypothesis of a nonlinear relationship with a first decrease and then an increase in the marginal effect.

Figure 8: Marginal effect of fintech innovation for the nonlinear model



Source: Author computation

At this stage, it is important to know if this marginal impact is sensitive to the heterogeneity of our sample.

Figure 9: Marginal effect of fintech innovation conditional to dummies for the linear model

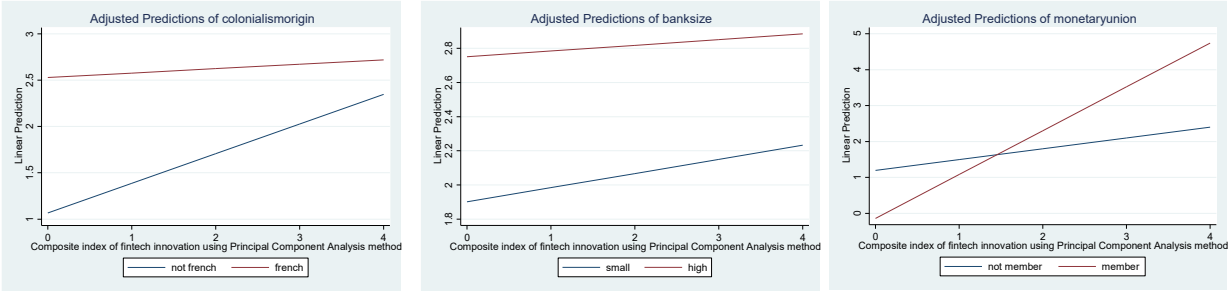
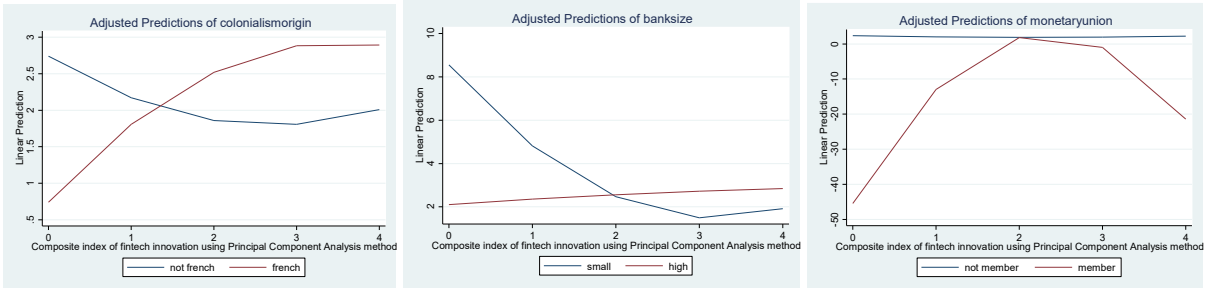


Figure 10: Marginal effect of fintech innovation conditional to dummies for the nonlinear model



Source: Author computation

The figures 9 and 10 above show that conditional to colonialism origin, for values of fintech innovation between 0 and 3.5, there is a convergence of the marginal impact; after there is a divergence. We have practically the same evolution when we consider the banking size. For the

monetary union membership, there is an absolute divergence. Overall, all these conditional marginal impacts confirm the nonlinear relationship. These post-estimations results the nonlinear model invite us to go beyond the finding of the existence of a non-linearity in quadratic and/or cubic forms with particular turning points, by estimating the thresholds points.

5.2.2. Fintech Innovation-bank fragility relation: a panel threshold regression

The output of the result of the panel threshold investigation is presented in tables 3and 4 bellows. The single threshold model estimator is 0.502 with a 95% confidence interval and an F statistics highly significant. Therefore, the U curve relationship is confirmed with the rejection of the linear model in favour of a double or triple-threshold model.

Table 3: Results of estimation of a single threshold

Estimating the threshold parameters: 1st ..... Done
Bootstrapping for threshold effect test: 1st ..... Done
Threshold estimator (level = 95):

model	Threshold	Lower	Upper
Th-1	0.502	0.496	0.513

Threshold effect test (bootstrap = 300):

Threshold	RSS	MSE	Fstat	Prob	Crit10	Crit5	Crit1
Single	1045.617	0.096	622.960	0.000	44.208	54.825	76.694

Source: Author computation

Considering the above results, we next directly fit a triple-threshold model. Unmistakably, the double-threshold model of 0.238 and 0.502 is accepted with probability value 0.97. Moreover, these thresholds make economic sense because they are within the range (-0.104 to 3.935) provided by the summary statistics. Thus, given the finding of the first step of our nonlinear investigation, we can observe that globally, before the threshold of 0.502 there is a negative relationship and after there is a positive relationship. The second step finding confirmed the cubic form of our equation with the implication of the existence of three regimes: a first increase until the first threshold, followed by a decrease until the second threshold, and finally an increase. To reinforce our conclusion, we ran an alternative set of regressions not reported here, excluding countries with fintech innovation performance less than 0.502 and found now a stabilizing impact. Table A6 in appendix presents the classification of countries based on these 3 regimes. The main economic implication of this result is that there is a minimum threshold of fintech innovation to perform if we want to have a stabilizing impact on the banking sector.

Table 4: Results of the estimation of multiple thresholds

Estimating the threshold parameters: 2nd ..... 3rd ..... Done
Bootstrapping for threshold effect test: 2nd ..... 3rd ..... Done
Threshold estimator (level = 95):

model	Threshold	Lower	Upper
Th-1	0.502	0.496	0.513
Th-21	0.502	0.496	0.513
Th-22	0.238	0.232	0.243
Th-3	2.581	2.574	2.638

Threshold effect test (bootstrap = 0 300 300):

Threshold	RSS	MSE	Fstat	Prob	Crit10	Crit5	Crit1
Single	1045.617	0.096	622.960	0.000	44.208	54.825	76.694
Double	1009.707	0.093	386.940	0.000	43.153	51.569	84.055
Triple	992.583	0.091	187.700	0.973	328.233	342.537	381.302

Source: Author computation

From this last result and consistent with the objective of this paper, it is important to verify if we have the same results conditional to selected variables.

5.3. Would investment, commercial openness, financial openness or monetary policy boost the effects of fintech innovation on bank fragility?

In this sub-section, we present the results of the investigation on the effect of investment, commercial openness, financial openness and monetary policy respectively on the relationship between fintech innovation and bank fragility. It consisted technically to implement a simultaneity test with the purpose to verify that the following 4 points can improve or reduce the impact of fintech innovation on bank fragility: investment; commercial openness; financial openness and monetary policy. Table 5 below reports the estimates of the conditional effect of fintech innovation. The results interpretation permit us to consider two different types:

For the first type, investment (column 1), commercial openness (column 2), and monetary policy (column 4) appears not to be useful in accompanying fintech innovation in reducing bank fragility. Firstly, the effect of fintech innovation conditional on the adoption of commercial openness policies is negative and significant. In other words, the effect of fintech innovation on bank fragility remains negative for countries that have adopted commercial openness. We turn to the effect of investment on the relation between fintech innovation and bank fragility and found also a negative relation. Finally, concerning monetary policy adoption, we also found a negative effect.

On the other hand, we observe a negative impact on bank fragility of fintech innovation when taken on its own; but when combined with financial openness (column 3), this impact becomes positive and significant at 1%. Thus, financial openness is a tool which can be used to reduce or change the negative impact of fintech innovation on bank fragility. This may suggest that the adoption of financial openness is a potential channel through which fintech innovation can help stabilize the banking system. The consequent recommendation is at least for the countries within the regime characterized by a negative relationship, to implement policies such as financial openness policies which can accompany financial innovation aiding the bank to benefit from it. However, this mechanism remains theoretically unclear and may deserve further analysis.

Table 5: Impact of fintech innovation on bank fragility: Simultaneity test

VARIABLES	(1) GMM Syst.	(2) GMM Syst.	(3) GMM Syst.	(4) GMM Syst.	(5) GMM Syst.
L.lnzscore	1.032***	1.006***	1.007***	1.018***	1.021***
	(0.00841)	(0.00912)	(0.00868)	(0.00839)	(0.00941)
Fintech innovation	-0.157***	0.0163	-0.155***	-0.0619***	-0.227***
	(0.0115)	(0.0289)	(0.0117)	(0.0115)	(0.0344)
Life insurance / GDP	0.0272***	0.0185***	0.0188***	0.0266***	0.0382***
	(0.00319)	(0.00300)	(0.00303)	(0.00309)	(0.00338)
GDP growth	0.00476**	-0.00185	-0.00116	-0.000542	0.00397*
	(0.00190)	(0.00192)	(0.00188)	(0.00201)	(0.00236)

Monetary policy	-0.000788	-0.00543***	-0.00186*	-0.0181***	-0.0161***
	(0.00112)	(0.00120)	(0.00113)	(0.00138)	(0.00142)
Financial openness	-2.6e-15***	-2.9e-15***	-2.4e-15***	-1.8e-15***	-0.8e-15***
	(3.4e-16)	(3.4e-16)	(3.4e-16)	(3.3e-16)	(1.5e-16)
Unemployment rate	0.0100***	0.00925***	0.00793***	0.0132***	0.0127***
	(0.00105)	(0.00104)	(0.00106)	(0.00109)	(0.00109)
Investment / GDP	-0.00209***	0.000206	0.000636**	0.00230***	-6.58e-05
	(0.000406)	(0.000273)	(0.000271)	(0.000289)	(0.000418)
Commercial openness	0.0329***	-0.0375***	-0.00229	0.0176*	0.0653***
	(0.0111)	(0.0136)	(0.0117)	(0.0107)	(0.0159)
Population growth	-0.0801***	-0.121***	-0.0727***	-0.124***	-0.108***
	(0.00880)	(0.0129)	(0.00873)	(0.00912)	(0.0130)
Human capital	0.232***	0.193***	0.490***	0.000411	0.248***
	(0.0429)	(0.0529)	(0.0579)	(0.0420)	(0.0617)
Innov * Invest	-0.00314***				-0.00362***
	(0.000388)				(0.000406)
Innov * Ccial		-0.0415***			0.0348***
		(0.00698)			(0.00886)
Innov * Fincial			2.7e-15***		1.2e-15***
			(3.7e-16)		(3.8e-16)
Innov * Monpol				-0.0150***	-0.0156***
				(0.000924)	(0.00115)
Observations	3,044	3,044	3,010	2,814	2,780
Number of id	527	527	527	481	481
AR(2) test	0.407	0.502	0.301	0.711	0.882
Hansen OID test	0.661	0.777	0.449	0.609	0.766

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

Overall, this emphasizes that investment, commercial openness and monetary policy are not a useful tool to change the negative impact of fintech innovation; while financial openness can help with a significant but almost null impact. Therefore, it is well-grounded to verify if our result is responsive to taking heterogeneity into account.

5.4. Fintech innovation and bank fragility: *does bank size, colonialism origin and monetary union membership Matter?*

Taking into account the entire sample assumes that we consider absolute homogeneity. However, the existence of heterogeneity is much more plausible for the following reasons: It is, therefore, appropriate for us to get around this problem by introducing dummies (binary variables) based on the following potential heterogeneities. This is an aspect which has not been exploited or has been less exploited in the works on our theme. We present here the result of the estimation of the baseline equation augmented with dummies variables effects.

Using the binary coding scheme, the coefficient on the bank size category variable in table 6 bellow indicates that countries with a large banking sector have an average impact of 2.9 points higher compared to countries with a small banking sector. Likewise, the countries colonized by France have on average an impact that is 1.9 points higher compared to countries that have known other colonizers. Finally, there is no significant impact when considering the belonging to a monetary union.

Table 6: Impact of fintech innovation on bank fragility: Heterogeneity test

VARIABLES	(1) MCO	(2) FGLS	(3) GMM Syst.
L.lnzscore			0.955***
			(0.00978)
Fintech innovation	-0.265***	-0.265***	-0.226***
	(0.0294)	(0.0293)	(0.0131)
Bank size	0.249***	0.249***	0.200***
	(0.0415)	(0.0414)	(0.0188)
Colonialism origin	0.997***	0.997***	0.312***
	(0.0536)	(0.0534)	(0.0265)
Monetary union membership	0.0335	0.0335	0.0513
	(0.0760)	(0.0759)	(0.0331)
Life insurance / GDP	0.0485***	0.0485***	-0.00577
	(0.00825)	(0.00823)	(0.00389)
GDP growth	-0.0326***	-0.0326***	-0.00664***
	(0.00467)	(0.00465)	(0.00215)
Inflation rate	0.000745	0.000745	0.00330***
	(0.00286)	(0.00285)	(0.00114)
Unemployment rate	0.00427*	0.00427*	0.0175***
	(0.00256)	(0.00255)	(0.00120)
Financial openness	-1.4e-14***	-1.4e-14***	-5.2e-15***
	(8.1e-16)	(8.1e-16)	(3.9e-16)
Investment / GDP	-0.00221***	-0.00221***	0.00219***
	(0.000645)	(0.000644)	(0.000297)
Commercial openness	-0.470***	-0.470***	-0.0639***
	(0.0285)	(0.0284)	(0.0133)
Population growth	-0.0951***	-0.0951***	-0.0678***
	(0.0268)	(0.0267)	(0.0113)
Human capital	2.676***	2.676***	0.864***
	(0.142)	(0.142)	(0.0645)
Constant	2.363***	2.363***	
	(0.175)	(0.174)	
Observations	2,793	2,793	2,780
R-squared	0.590		
Number of ids		481	481

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

The results of the sample-based estimate presented in table 7 bellow confirm the results of the overall estimate for the origin of the colonizer and the size of the banking sector. However, this new estimate makes it possible to see more clearly and thus to supplement the previous results; the positive and significant impact of fintech innovation for countries members of monetary unions becomes negative and less significant for the countries which are not members.

Table 7: Regression results based on different groups

	Monetary Union		Colonialism origin		Banking sector size	
	(1)	(2)	(3)	(4)	(5)	(6)
	member	not_member	french	not_french	high	small
Fintech innovation	2.569***	-0.246***	0.299***	-0.298***	0.227***	-0.539***
	(0.247)	(0.019)	(0.049)	(0.017)	(0.007)	(0.066)
GDP growth	-0.003	-0.083***	0.012***	-0.040***	0.001	-0.067***
	(0.002)	(0.006)	(0.004)	(0.005)	(0.002)	(0.007)
Inflation rate	-0.006***	-0.006**	0.015***	0.006**	0.021***	-0.021***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
Unemployment rate	0.046***	-0.005**	0.048***	-0.000	-0.013***	-0.017***
	(0.013)	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)
Financial openness	0.000***	-0.133***	-0.000***	-0.536***	0.503***	-0.000***
	(0.000)	(0.018)	(0.000)	(0.023)	(0.024)	(0.000)
Investment / GDP	-0.001***	0.004***	-0.008***	0.007***	0.015***	-0.004***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Commercial openness	-0.458***	-0.424***	-0.375***	-0.911***	-1.048***	-0.045
	(0.046)	(0.042)	(0.033)	(0.040)	(0.061)	(0.046)
Population growth	0.538***	-0.556***	0.139***	-0.505***	0.725***	-0.654***
	(0.038)	(0.032)	(0.041)	(0.033)	(0.047)	(0.052)
Human capital	-2.500***	3.546***	-0.159	4.879***	-1.804***	0.862***
	(0.181)	(0.176)	(0.123)	(0.172)	(0.067)	(0.181)
Constant	-1.529***	2.975***	2.807***	2.837***	7.705***	5.136***
	(0.482)	(0.292)	(0.164)	(0.264)	(0.216)	(0.241)
Obs.	191	2716	567	2340	1060	1847

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

5.5. Robustness check

5.5.1. Impact of financial instability on bank fragility

Building on the literature on fintech innovation and financial instability (as well as financial instability and bank crisis), we intend to verify if financial instability can be positively linked to bank fragility. The results presented in table 8 below show a negative relationship between these two variables meaning that financial instability increases bank fragility. We find that for every additional level of financial instability, the expected fragility level of the banking sector increases by 0.02 average, holding all other variables constant. This last result is not only statistically significant but also economically significant independently to the estimation method. It is conclusive and confirms the theory of the relationship between financial stability and bank fragility through a banking crisis. So we can attest this theory being confirmed by our empirical

estimation showing a negative impact; therefore fighting bank fragility is not against fighting financial instability.

Table 8: Impact of fintech innovation on bank fragility: Financial instability test

		(1) OLS	(2) FGLS	(3) GMM
	L.zscore			1.016***
				(0.00868)
	pca1	-0.161***	-0.161***	-0.151***
Bank variables		(0.0290)	(0.0289)	(0.0123)
	financialinstab	-0.0211***	-0.0211***	-0.00304**
		(0.00280)	(0.00280)	(0.00119)
	lifeinsurancevol	0.0784***	0.0784***	0.0137***
		(0.00694)	(0.00693)	(0.00305)
	gdpgrowth	-0.0513***	-0.0513***	-0.00907***
		(0.00496)	(0.00495)	(0.00223)
	unemployment	-0.0201***	-0.0201***	0.0113***
		(0.00249)	(0.00248)	(0.00112)
	ouverturefincire	-7.5e-15***	-7.5e-15***	-2.5e-15***
		(7.6e-16)	(7.6e-16)	(3.4e-16)
Control variables	grossfixcapform	-0.00484***	-0.00484***	0.00183***
		(0.000689)	(0.000687)	(0.000300)
	lnouvcciale	-0.330***	-0.330***	-0.00474
		(0.0279)	(0.0278)	(0.0116)
	populationgrowth	-0.270***	-0.270***	-0.0715***
		(0.0239)	(0.0238)	(0.00887)
	eduseconenrol	1.469***	1.469***	0.454***
		(0.136)	(0.136)	(0.0598)
	Constant	3.642***	3.642***	
		(0.143)	(0.142)	
	Observations	2,793	2,793	2,780
	R-squared	0.515		
	Number of ids		481	481

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

Additional robustness check is linked to our nonlinear investigation. It consisted to verify if we have a U-curve relationship everywhere.

5.5.2. Is Fintech Innovation-bank fragility relation U-shaped everywhere?

Considering the findings presented in table 9 below, we can observe that the impact of fintech innovation on bank fragility differs substantially among the different types and these findings are robust to the presence or absence of the non-linear fintech innovation impact.

Table 9: Results of U curves regression-based conditional to specific groups

	Monetary Union		Colonialism		Banking sector size	
	(1)member	(2)not	(3)french	(4)not	(5) high	(6)small
Fintech innovation	8.700*	-0.906***	2.268***	-1.105***	-9.941	-5.638***
	(5.205)	(0.104)	(0.196)	(0.089)	(0.000)	(0.281)
FI squared	-1.384	0.079***	-0.253***	0.097***	0.936	0.789***
	(1.174)	(0.012)	(0.025)	(0.010)	(0.000)	(0.043)
GDP growth	-0.003	-0.076***	0.009**	-0.030***	-0.027	-0.075***
	(0.002)	(0.006)	(0.004)	(0.005)	(0.000)	(0.006)
Inflation rate	-0.006***	-0.005*	0.013***	0.007***	-0.008	-0.027***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.000)	(0.003)
Unemployment rate	0.043***	-0.004*	0.045***	0.000	-0.132	0.000
	(0.013)	(0.002)	(0.002)	(0.002)	(0.000)	(0.003)
Financial openness	0.000***	-0.144***	-0.000	-0.525***	0.532	-0.000***
	(0.000)	(0.018)	(0.000)	(0.023)	(0.000)	(0.000)
Investment / GDP	-0.001***	0.004***	-0.007***	0.007***	0.016	-0.003***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Commercial openness	-0.444***	-0.367***	-0.453***	-0.810***	-1.362	-0.124***
	(0.047)	(0.042)	(0.031)	(0.041)	(0.000)	(0.043)
Population growth	0.548***	-0.695***	0.319***	-0.720***	2.453	-0.511***
	(0.039)	(0.038)	(0.041)	(0.040)	(0.000)	(0.048)
Human capital	-2.620***	3.375***	-0.361***	4.566***	-5.311	1.294***
	(0.207)	(0.177)	(0.115)	(0.172)	(0.000)	(0.168)
Constant	-8.276	4.289***	-0.299	4.522***	41.050	12.123***
	(5.742)	(0.354)	(0.336)	(0.317)	(0.000)	(0.437)
Obs.	191	2716	567	2340	1060	1847

Source: Author calculation. *** p<0.01, ** p<0.05, * p<0.1. Windmeijer (2005) standard errors in parentheses.

6. Conclusion and economic policy suggestions

The objective of this paper was to rigorously investigate the impact of fintech innovation on bank fragility. First, we assessed the baseline effect of fintech innovation on banking fragility. The idea here was, therefore, to ask first of all whether fintech innovation, considered as an exogenous shock in our model, significantly influences bank fragility; and if so, whether the relationship is linear or nonlinear. Mainly, we sought to verify the existence of a *Kuznets curves* bank fragility by analyzing the potential non-linear relationship to estimate the threshold (s). Then, in a second step, still starting from the basic model, we proceeded to the test of the hypothesis of simultaneity; it was a question of verifying whether taking into account certain factors could change the situation in the impact of fintech innovation on bank fragility. These factors included financial openness, trade openness, monetary policy and investment.

In a third step, we checked the heterogeneity of our sample to verify the influence that this could have on our results. In fact, with regards to and to contribute to the literature, it seemed necessary for us to take into account the instability of the global measurement of the financial system, the introduction of dummies and the estimation by group-based on membership in a monetary union, the colonizer origin, and finally the size of the banking sector. In general, this involved dissociating the effect on our measurement from fintech innovation, taking specific account of the size on the one hand and the activity on the other. The objective being to isolate from these two aspects, which is the most important to understand bank fragility.

The result of our baseline investigation showed that there is a negative and significant impact of fintech innovation and bank fragility. In other words, fintech innovation is increasing the fragility of the banking system in SSA. These results remain robust across different bank fragility proxies. When non-linearity is considered, this negative impact remains and we found a

nonlinear relation. Beyond this finding of nonlinearity and turning points, we detected that the thresholds points are 0.503 and 0.207 with alternative regimes of stabilizing and destabilizing impacts of fintech innovation.

Moreover, the results highlighted also that the macroeconomic environment is important in explaining bank fragility and suggested that public policy should take into account some specific destabilizing consequences on the banking system. Besides, the simultaneous hypothesis test studied the innovation-fragility nexus conditional to some relevant variables and revealed that investment, commercial openness and monetary policy are not a useful tool to change the negative impact of fintech innovation; while financial openness can help with a significant but almost null impact.

Lastly, the robustness test with sub-sample formed based on the previous results illustrates further that the sample composition may have a strong impact on the observed associations between fintech innovation and bank fragility. This can explain some controversies reported in previous empirical papers. The latter, in turn, stresses the importance of understanding sample characteristics as well as fintech innovation along with bank fragility measurement approach before providing policy suggestions. The comparative analysis validated our heterogeneity hypothesis; countries with the high size banking sector, colonialized by France and members of monetary union performs better than the others in terms of bank solidness. Indeed, using the binary coding scheme, the coefficient of the category variable relating to the size of the bank indicates that countries with a large banking sector have on average an impact that is 2.9 points higher compared to countries with a small banking sector. Likewise, the countries colonized by France have on average an impact that is 1.9 points higher compared to countries that have known other colonizers. And finally, there is no significant impact when considering whether the belonging to a monetary union. These results indicate that suitable fintech innovation policy even between the same regions could be rather different. Financial instability appeared also to increase bank fragility.

Overall, we observe that the association between fintech innovation on bank fragility remains a complex issue which needs to consider the potential non-linearity. It is not possible to develop one-size-fits-all policy suggestions. The identification of suitable regulatory approaches relies on the proper definition of the type of fintech innovation being targeted as well as on a sufficiently diverse sample of banks. In the context of SSA, there exist clear signs that countries member to a monetary union and those not members may require a different policy response.

Given the existing empirical literature associated with the study of the determinants of bank fragility, our study certainly confirms the central role of the effective level of financial innovation and also of the satellite variables which have a direct or indirect impact on the fragility of banks through fintech innovation. However, the results we obtain are slightly different from those obtained so far. We highlighted that financial innovation is not an "absolute" factor of bank fragility. This contrasts and/or completes the conclusions of numerous econometric analyses which underlined the absolute nature of this impact (Beck et al., 2016). This result is particularly interesting since it shows that what matters to combat bank fragility is not to remember that fintech innovation has a negative impact, but to go beyond it with not only considered a threshold beyond which financial innovation becomes a weapon, but also the conditions under which it becomes useful for this fight.

Overall, these results are valid for the application of a large number of robustness tests relating to the consideration of unobservable heterogeneity within our sample, the possible presence of a simultaneity bias at the level of certain control variables included in our model, autocorrelation and alternative distribution of errors, the modification of the structure of our database, as well as the introduction of additional determinants of banking fragility.

Annexe

Table A1: List countries within the sample.

South Africa - Benin - Burkina-Faso - Botswana - Burundi - Cameroon - Cape Verde – Ivory coast - Congo - Djibouti - Gabon – Gambia - Ghana - Guinea Bissau - Equatorial Guinea - Kenya - Madagascar - Malawi - Mali - Mauritania - Mauritius - Mozambique - Namibia - Nigeria – Central African Republic - Rwanda - Sao Tome & Principe - Senegal - Seychelles - Sierra Leona - Soudan - Swaziland - Chad - Togo.

Source: Authors construction

Table A2: Descriptive Statistics.

	Observations	Means	Standard deviation	Minimum	Maximum
ATMS	560	8.271429	14.02737	0	69
CONBANK	560	5.9375	8.80994	0	55
DCPS	560	20.04286	17.70949	0	105
ICS	560	41.175	40.80805	0	171

Source: Authors construction

Table A3: Correlation matrix of simple factors of the fintech innovation index

	ATMS	CONBANK	DCPS	MCS	INDEX
ATMS	1.0000				
CONBANK	0.6823	1.0000			
DCPS	0.5992	0.4958	1.0000		
ICS	0.6818	0.4802	0.4340	1.0000	
INDEX	0.8183	0.8558	0.7705	0.6343	1.0000

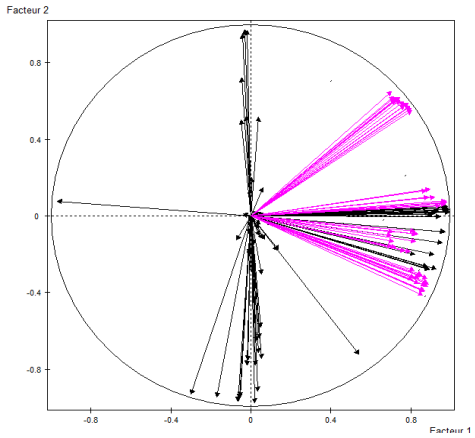
Source: Authors construction

Table A4: Eigenvalue histogram.

NUMERO	VALEUR PROPRE	POURCENT.	POURCENT. CUMULE	
1	15.2442	63.85	63.85	**********
2	3.3628	14.08	77.94	**********
3	2.1720	9.10	87.03	**********
4	1.1060	4.63	91.67	******
5	0.5997	2.51	94.18	****

Source: Authors construction

Figure A1: Correlation circle of variables and groups of variables in the factorial plane.



Source: Authors construction

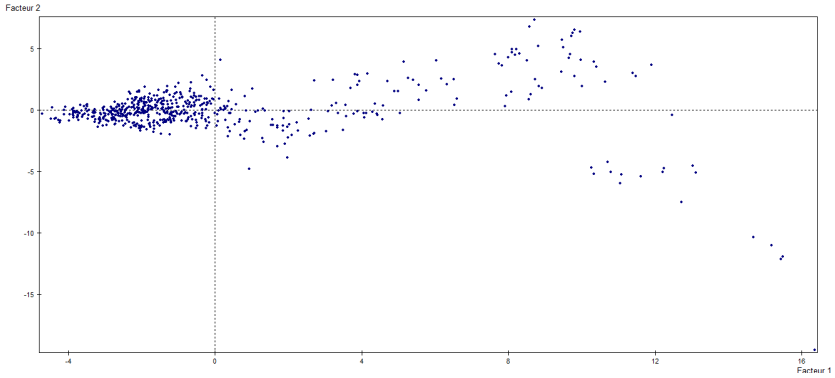
Table A5: Result of the construction of the fintech innovation index by the ACP method.

Principal Components	Proportion	Cumulative Proportion	Eigen Value
First PC	63.85	63.85	15.24
Second PC	14.08	77.94	3.363
Third PC	9.10	87.03	2.172
Fourth PC	4.63	91.67	1.106

Year	ATMS	CONBANK	DCPS	ICS	Total weight
2000	0,00	0,37	0,24	0,38	1
2001	0,00	0,37	0,25	0,38	1
2002	0,00	0,35	0,28	0,37	1
2003	0,25	0,27	0,23	0,25	1
2004	0,30	0,26	0,21	0,23	1
2005	0,30	0,26	0,21	0,23	1
2006	0,29	0,27	0,21	0,24	1
2007	0,30	0,26	0,21	0,23	1
2008	0,30	0,28	0,19	0,23	1
2009	0,29	0,27	0,22	0,22	1
2010	0,30	0,29	0,21	0,20	1
2011	0,31	0,28	0,21	0,20	1
2012	0,33	0,28	0,20	0,19	1
2013	0,32	0,27	0,21	0,20	1
2014	0,32	0,27	0,21	0,21	1

Source: Author construction. PC: Principal Component. Automated Teller Machines (ATMs); commercial bank branches (CONBANK); Domestic credit to the private sector by banks (DCPS); Insurance Company Assets (ICS).

Figure A2: Cloud of individuals (country)



Source: Authors construction

Table A6: Countries classification based on the three regimes of the threshold regression result.

Countries with fintech innovation above 0.502	South Africa; Mauritius; Namibia; Seychelles; Cape Verde.
Countries with fintech innovation less than 0.238	Botswana; Swaziland; Sao tome and Principe; Nigeria; Togo; Mauritania; Gabon; Mozambique; Cote d'Ivoire; Senegal; Burkina Faso; Benin; Ghana; Mali; Malawi; Burundi; Sudan; Cameroun; Guinea Bissau; Equatorial Guinea; Madagascar; Rwanda; Central Africa Republic; Congo; Guinea; Chad.
No data	Gambia; Sierra Leone; Eritrea; Djibouti; South Sudan.

Source: Author construction

Table A7: Regression results (placebo effect)

	(1) zscore	(2) banksize	(3) colonialismorigin	(4) monetaryunion	(5) gdpgrowth
Fintech innovation	0.234***	0.524***	-0.068***	-0.097***	-0.716***
	(0.008)	(0.003)	(0.004)	(0.004)	(0.032)
_cons	1.548***	-1.236***	0.500***	0.503***	7.105***
	(0.028)	(0.011)	(0.014)	(0.012)	(0.111)
Obs.	5136	6088	6088	6088	5692

Source: Author calculation. Windmeijer (2005) standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A8: Data definition, source and descriptive statistics

Category	Variable	Description	Source	Obs.	Mean	St.Dev
Dependent variables	Banking fragility 1	Z-score: Risk of bank failure (Probability)	a	9622	13.077	10.421
	Banking fragility 2	Bank return: Return On Average Equity (ROAE)	a	2853	1373.461	794.989
Main Variable	Fintech innovation	Composite index using the principal component analysis method	b	6088	3.1132	1.357
Dummies variables	Banking size	Small, medium and high size of the banking sector	b	10598	.353	.762
	Language	Language origin linked to the colonization	b	10896	.275	.446
	Member	membership of a monetary union	b	10896	.181	.385
Composed variables	Innovouv	Fintech innovation * Financial openness	c	5106	-3.406	20.047
	Innovpm	Fintech innovation * Monetary policy	c	5664	.3	5.784
	Innovouvccial	Fintech innovation * Commercial openness	c	5715	-7.6e+12	4.1e+13
	Innovinvest	Fintech innovation * Investment	c	5203	-1.233	11.512
Bank specific variables	Insurance	Insurance company asset	a	5334	133.029	67.559
	Loans	Net Loans Total Assets	a	2739	47	20.6
	Automated payments	Automated teller machines	a	6213	14.745	18.471
	Banking activity	Domestic credit to the private sector of GDP ratio	a	10598	39.121	48.098
	Bank return	Return On Average Equity (ROAE)	a	2853	1373.461	794.989
	Net interest margin	Net Interest Rate Margin	a	2766	1245.681	719.488
	Insurance ratio	Life insurance premium volume / GDP	a	8461	2.868	4.8
Macroeconomic environment variables	Production growth	The annual GDP growth rate	d	10364	4.872	4.931
	Monetary policy	indexed by the inflation rate	d	9358	7.874	6.5
	Unemployment	Annual Unemployment rate	d	10214	12.327	8.686
	Financial openness	De Jure Financial openness	d	10443	5.5e+12	3.4e+13
	Investment	indexed by Gross Fixed Capital Formation / GDP	d	9113	14.113	100.963
	Commercial openness	Exportation + Importation / GDP	e	10274	4.123	.608
	Population	Population growth rate	d	10261	2.248	.793
	Human Capital	Secondary school enrollment / GDP	d	7399	.909	.192

Source: Author construction.
Note: a: Bankscope database; b: author construction; c: author computation; d: World development indicator; e: Chin & Ito database.

Table A9: First matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) lnzscore	1.000								
(2) fintechinnov	0.505	1.000							
(3) banksize	0.515	0.898	1.000						
(4) colonialismorigin	0.238	-0.214	-0.291	1.000					
(5) monetaryunion	0.079	-0.338	-0.267	0.718	1.000				
(6) innovfbcf	0.222	0.479	0.434	-0.161	-0.217	1.000			
(7) innovouvccial	0.529	0.995	0.883	-0.178	-0.315	0.468	1.000		
(8) innovouv	-0.128	0.166	0.126	-0.350	-0.471	-0.029	0.134	1.000	
(9) innovpm	0.429	0.867	0.774	0.000	-0.066	0.396	0.868	0.003	1.000

Source: Authors construction

Table A10: Second matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) lnzscore	1.000										
(2) fintechinnov	0.584	1.000									
(3) lifeinsurancep~o	0.590	0.912	1.000								
(4) gdpgrowth	-0.414	-0.422	-0.358	1.000							
(5) infationconsum~l	-0.205	-0.399	-0.342	-0.235	1.000						
(6) unemployment	0.330	0.695	0.739	-0.283	-0.218	1.000					
(7) ouverturefincire	0.011	-0.077	-0.069	-0.102	-0.109	0.068	1.000				
(8) grossfixedcapi~n	-0.255	-0.290	-0.203	0.429	-0.212	-0.248	-0.049	1.000			
(9) lnouvcciale	-0.126	0.178	-0.011	-0.026	-0.106	0.083	-0.167	-0.092	1.000		
(10) populationgro~h	-0.578	-0.721	-0.601	0.350	0.340	-0.308	-0.135	0.202	-0.034	1.000	
(11) eduseconschoo~c	0.515	0.768	0.691	-0.475	-0.270	0.666	0.360	-0.321	0.209	-0.629	1.000

Source: Authors construction

Table A11: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) zscore	1.000								
(2) fintechinnov	0.333*	1.000							
	(0.000)								
(3) banksize	0.429*	0.893*	1.000						
	(0.000)	(0.000)							
(4) colonialismorigin	0.243*	-0.204*	-0.240*	1.000					
	(0.000)	(0.000)	(0.000)						
(5) monetaryunion	0.109*	-0.329*	-0.221*	0.729*	1.000				
	(0.000)	(0.000)	(0.000)	(0.000)					
(6) innovfbcf	0.265*	0.476*	0.416*	-0.145*	-0.193*	1.000			
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
(7) innovouvccial	0.496*	0.995*	0.881*	-0.131*	-0.287*	0.467*	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
(8) innovouv	-0.096*	0.135*	0.098*	-0.331*	-0.445*	-0.034*	0.102*	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.015)	(0.000)		
(9) innovpm	0.386*	0.841*	0.737*	0.009	-0.062*	0.387*	0.838*	-0.006	1.000
	(0.000)	(0.000)	(0.000)	(0.498)	(0.000)	(0.000)	(0.000)	(0.647)	

* shows significance at the .10 level

Source: Authors construction

Table A12: Country-based regression results (Impact of fintech innovation on bank fragility)

country	Fintech innovation	_cons	R^2
Benin	-0.058	2.935	0.002
Burkina Faso	0.386	1.329	0.089
Burundi	2.683	-3.057	0.429
Chad	-3.317	9.282	0.271
Cameroun	-1.379	5.684	0.229
Cape Verde	0.108	2.821	0.590
Central Africa republic	1.415	-0.488	0.132
Congo	-0.042	1.442	0.000
Cote d'Ivoire	-2.686	9.068	0.472
Equatorial Guinea	-0.280	1.853	0.050
Guinea	-0.775	3.326	0.006
Gabon	**-0.860**	**4.565**	**0.795**
Ghana	1.242	-0.432	0.224
Guinea Bissau	-1.757	5.416	0.422
Madagascar	-1.932	6.727	0.231
Malawi	2.022	-2.138	0.659

Mali	0.809	1.054	0.020
Mauritius	-0.411	4.680	0.235
Mozambique	0.331	-0.134	0.112
Namibia	-0.008	1.779	0.001
Nigeria	**-2.021**	**5.952**	**0.785**
Senegal	1.141	0.964	0.572
Seychelles	0.211	1.402	0.081
South Africa	0.013	2.874	0.021
Sudan	2.878	-3.397	0.261
Swaziland	-0.292	3.603	0.409
Togo	**-2.036**	**6.429**	**0.750**

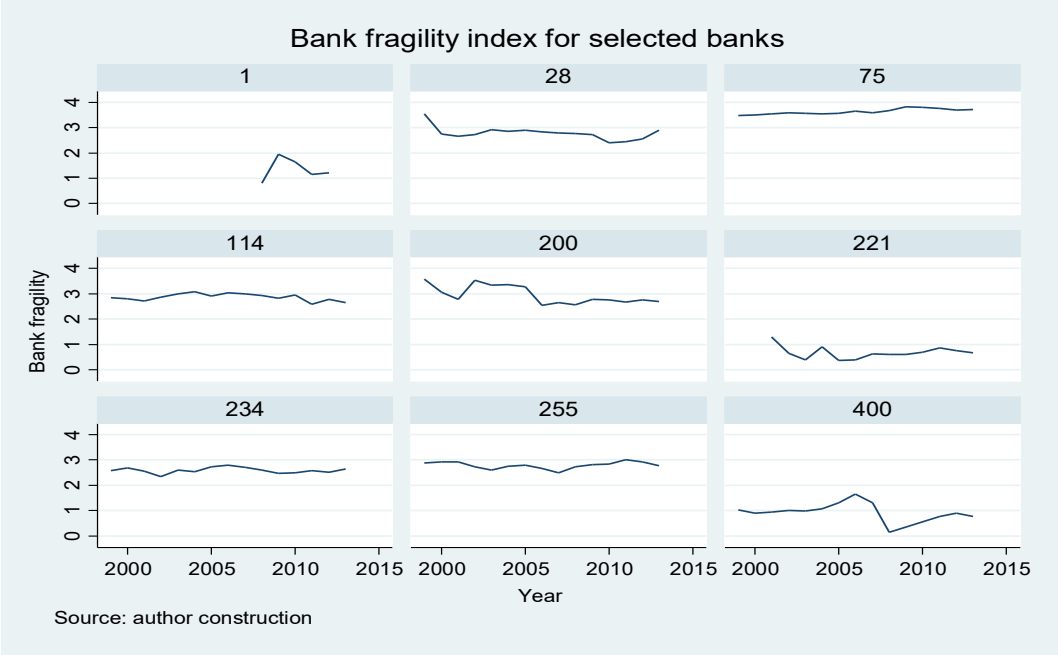
Source: Authors construction

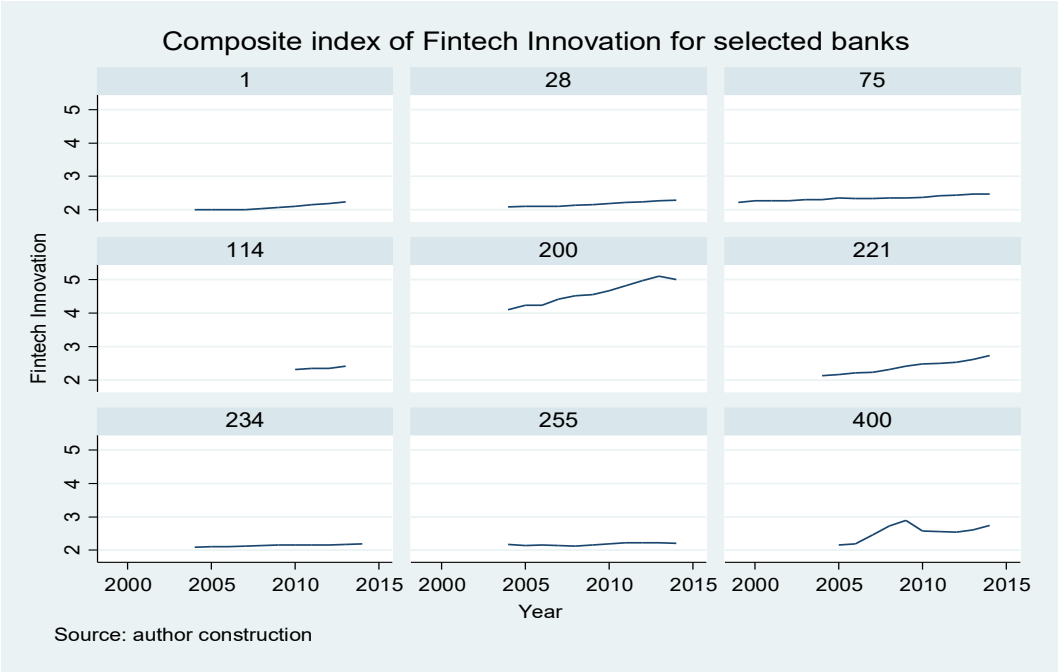
Table A13: Summary statistics (Bank fragility & Financial innovation): by (country)

	Banking fragility					Fintech innovation				
Country	**N**	**mean**	**sd**	**min**	**max**	**N**	**mean**	**sd**	**min**	**max**
Benin	150	2.803	.084	2.59	2.917	143	2.29	.063	2.186	2.417
Botswana	270	2.991	.358	2.434	3.476	11	3.281	.282	2.799	3.525
Burkina Faso	165	2.196	.169	1.704	2.417	44	2.3	.056	2.228	2.381
Burundi	135	2.793	.135	2.49	3.014	99	2.178	.033	2.13	2.223
Chad	65	2.669	.154	2.32	2.95	55	2.011	.032	1.975	2.084
Cameroun	285	2.779	.257	2.394	3.548	209	2.168	.069	2.08	2.287
Cape Verde	40	3.304	.024	3.279	3.344	88	3.967	.627	2.934	4.609
Central Africa rep	22	2.44	.204	2.132	2.867	20	2.077	.054	2.033	2.191
Congo	130	1.355	.396	.814	1.944	260	2.076	.085	1.994	2.241
Cote d'Ivoire	360	2.867	.14	2.578	3.083	100	2.356	.037	2.314	2.414
Djibouti	75	2.454	.263	2.072	3.054	0	.	.	.	.
Equatorial Guinea	16	1.264	.166	.925	1.472	26	2.164	.191	1.971	2.504
Eritrea	15	1.878	.122	1.753	2.028	0	.	.	.	.
Guinea	247	1.712	.369	1.157	2.347	209	2.058	.05	1.996	2.169
Gabon	135	2.59	.218	2.289	3.193	99	2.401	.13	2.268	2.693
Gambia	140	1.916	.158	1.703	2.15	0	.	.	.	.
Ghana	690	2.234	.218	1.801	2.571	506	2.233	.082	2.11	2.373
Guinea Bissau	10	1.451	.377	.818	1.867	8	2.167	.073	2.079	2.265
Madagascar	120	2.589	.113	2.344	2.795	88	2.139	.031	2.088	2.189
Malawi	315	2.316	.285	1.815	3.108	231	2.183	.094	2.032	2.301
Mali	165	2.862	.195	2.387	3.307	104	2.19	.03	2.162	2.359
Mauritania	195	3.389	.15	3.178	3.76	26	2.41	.018	2.392	2.428
Mauritius	390	2.956	.353	2.543	3.589	286	4.605	.326	4.101	5.101
Mozambique	273	.677	.239	.376	1.297	231	2.392	.189	2.119	2.723
Namibia	196	2.22	.753	1.516	3.501	126	4.04	.637	2.955	4.658
Nigeria	1508	.981	.339	.134	1.644	1160	2.545	.223	2.147	2.895
Rwanda	165	2.062	.284	1.419	2.472	22	2.096	.006	2.09	2.103
Sao tome	0	.	.	.	.	33	2.633	.412	2.171	3.191
Senegal	210	3.628	.105	3.474	3.813	205	2.349	.075	2.216	2.568
Seychelles	56	2.243	.226	1.858	2.589	70	4.018	.394	3.553	4.774
Sierra leone	240	1.775	.192	1.525	2.178	0	.	.	.	.
South Africa	1680	3.067	.289	2.692	3.935	1120	5.6	.509	4.936	6.226
Sudan	510	2.746	.359	1.961	3.205	373	2.175	.064	2.045	2.254
Swaziland	120	2.415	.731	.767	3.006	88	2.963	.267	2.446	3.45
Togo	168	1.334	.549	-.104	2.196	48	2.48	.086	2.36	2.59
South Sudan	75	2.746	.361	1.961	3.205	0	.	.	.	.

Source: Authors construction

Figure A3: Banking fragility and Fintech innovation curves for selected banks of some countries

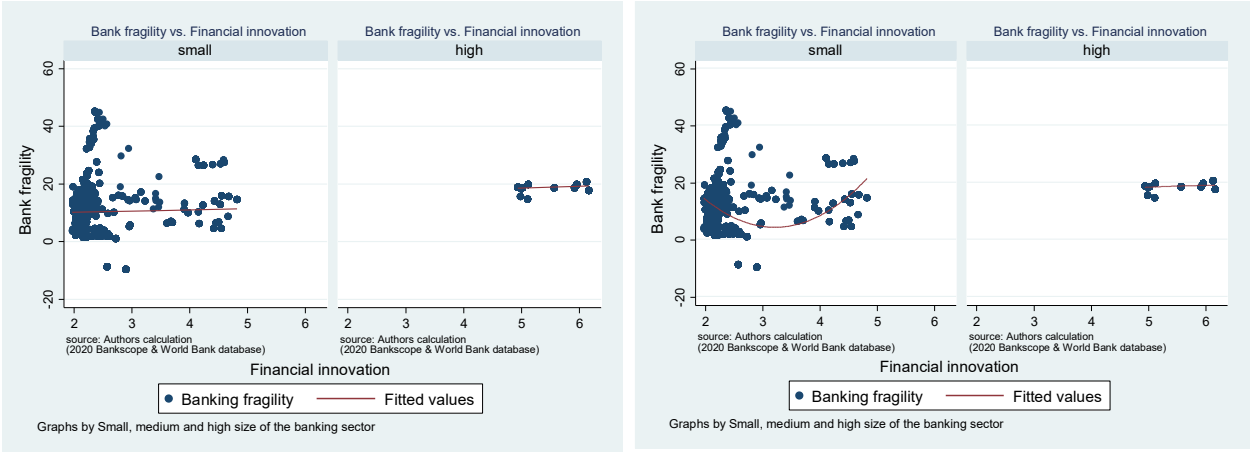




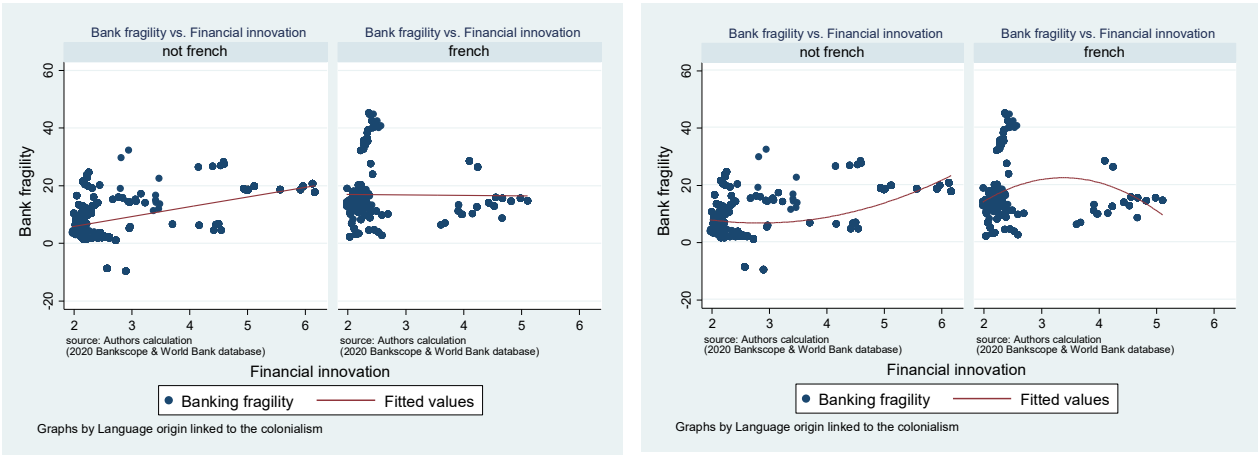
Notes : 1 "BGFIBank Congo", 28 "BICEC Cameroon", 75 "CS Senegal", 114 "BIAO Ivory Coast", 179 "BIM Mauritania", 221 "LFS Mozambic", 234 "BSBM Madagascar", 255 "IB Burundi", 333 "ICB Sierra Lione"

Figures A4: Grouping Bank fragility vs. Fintech innovation plots

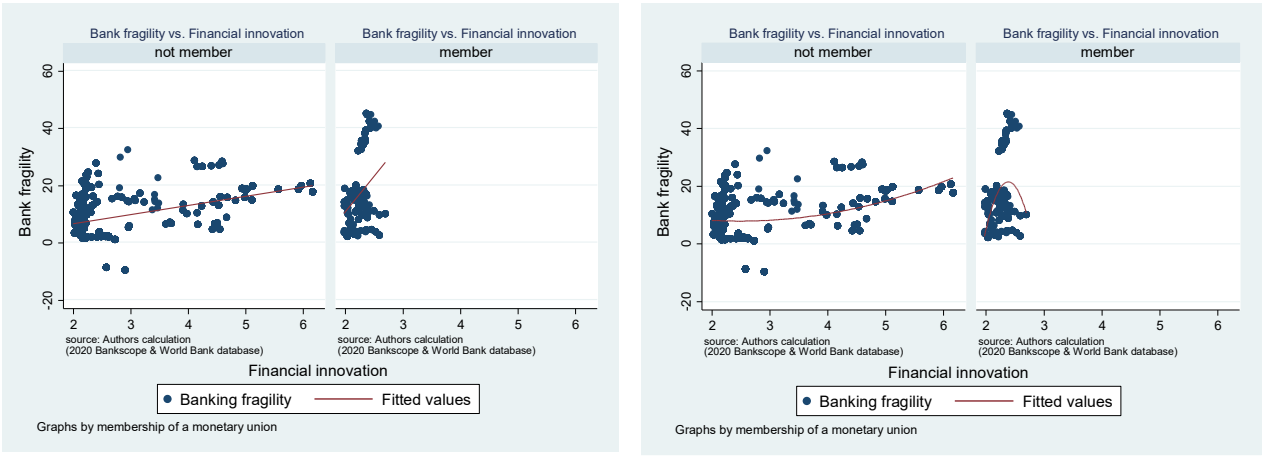
Linear and quadratic fits based on the size of the banking sector



Linear and quadratic fits based on the colonialization by France or not



Linear and quadratic fits based on Monetary Union membership or not



Source: Author construction

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