A network contagion approach for a climate stress test of European banks

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Abstract

The aim of this paper is to test if the European banking sector is resilient to losses in loans to economic activities exposed to climate risks or the energy transition. This paper presents a banking stress test methodology for European banks, focusing on loan exposures to economic activities likely to be impacted by the risks associated with climate change and the energy transition. First a network of contagion through the real economy is used incorporating the structure of the global production chain; secondly, two network mechanisms of financial contagion are considered: indirect contagion through adjustments in the price of assets and direct contagion in the interbank market. The results of the stress tests show that when direct and indirect contagion are allowed a crisis in the European banks is possible, especially if sectors such as construction and manufacturing are hit by climate and transition risks.

Keywords: Bank stress test. Climate change risks. Transition risks. Direct and indirect contagion.
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1. Introduction

Climate change will represent a challenge in the coming decades in many areas, including the stability of the financial system. In particular, in Europe, climate change will endanger the banking system by menacing assets' physical integrity and impacting vulnerable economic activities. In addition, since the transition to a low carbon economy necessary to fight climate change requires a total transformation of the productive system, sudden changes in the price of assets triggered by this rapid transition may also represent a risk to the stability of the banking system. Since the banking sector has been shown to be a deeply integrated system with dangerous systemic dynamics, coordinated policy and regulation will be essential. The bank stress test proposed will focus on the contagion dynamics that may be able to generate a widespread financial crisis. Events in the Great Financial Crisis (GFC) showed that problems in a few asset classes can generate a general disruption of the global financial system.

In this context, this research project develops a banking stress test methodology for European banks, focusing on exposures to economic activities likely to be affected by the risks associated with climate change. The methodology developed stands out for incorporating two mechanisms of contagion: indirect contagion through adjustments in the price of assets and direct contagion in the inter-bank market. This research project combines data from ordinary stress test exercises carried out by the European Banking Authority (EBA). Additionally, a matrix of exposures is constructed for common marketable positions (driving indirect contagion) and a matrix for direct positions in the inter-bank market (direct contagion).

Particularly this stress test exercise shows the level of losses that the banking system can take in the exposures towards climate vulnerable non-financial corporations (NFC). The paper shows that since climate change economic risks and transition to a low carbon economy economic risks in Europe are expected to be localized, they are not likely to cause a systemic banking crisis due to the initial asset valuation deterioration. However, the results of the stress tests show that when direct and indirect contagion are taken into account, a crisis in the European banks is possible, especially if the energy generation industry or industrial sectors such as manufacturing of road transport equipment suffer during a badly managed transition to a low carbon economy.

To the best of my knowledge, this paper presents the first European bank stress exercise of climate related risk with focus exposures to economic activities at bank level with direct and indirect contagion. We use the opportunity that arose when detailed sector exposures were released by the European Banking Authority.

The bank stress test scenario quantifies the potential exposure of financial institutions, departing from their exposure to different sectors of the economy to indirect contagion arising from deleveraging of assets in stress scenarios. The bank stress test exercise captures spillovers across portfolios arising from deleveraging in stress scenarios. We depart from sector level exposures as input of a bank stress test exercise with indirect financial contagion through fire sales of marketable commonly held assets and direct contagion through the inter-bank system. An inter-bank network is extrapolated from real exposures data using a

process of total exposure re-balancing, using an exposure link assignment allocation method through a proportional fitting algorithm.

2. The role of the banking industry in climate change and the transition to a low carbon economy

To assess the role of the banking system in the transition to a low carbon economy and in the climate change dominated future has become a central discussion on banking institutions, regulators, supervisors and politicians. In this context, generally speaking the financial system has two main tasks to perform: channel private funds to enable the investments required for the transition to a low carbon economy and simultaneously stay resilient in a challenging environment dominated by physical and transition risks.

The regulators are aiming for the standardization and implementation of rules aiming for greater transparency in climate related claims of financial securities. This is essential so a market for green securities can emerge in order to channel private funds for the transition to a low carbon economy. In this area of political action we must include the regulation of environmentally friendly financial instruments such as green bonds. A green bond is a type of fixed-income instrument that is specifically earmarked to raise money for climate and environmental projects. A debate is rising around the role of central banks in the transition to a low carbon economy. Particularly, it is debated if central banks should consider the introduction of investments in the fight against climate change as a new policy objective of monetary policy. This would require, for example, to amend the rules defining the scope of capital requirements and assets eligible as collateral for monetary policy lending to take account of climate (for example the ECB's corporate sector purchase programme – CSPP). However critics argue that it will be difficult to lead monetary policy around more than two priorities.

Nevertheless central banks must face climate change and the transition to a low carbon economy even if they remain focused on their traditional objectives. The traditional mandates given to central banks are price stability and the stability of the financial sector. Hence central banks will face climate issues directly if they affect inflation, for example, through inflationary pressures in agricultural products or energy commodities. Also, since physical and transition risks will impact financial assets, central banks will have to include them in their risk accounting and managing frameworks. In order to do so, the central banks must develop comprehensive methodologies to identify, measure, and evaluate the significance of such risks. Once this process is completed, central banks will have to incorporate environmental risks into capital requirements or collateral frameworks. However, gaining a deeper understanding of these potential pathways requires the development of a robust methodology to accurately assess the impact of climate change on the credit risk of eligible assets.

3. Introduction to bank stress tests

Stress tests have become well established tools for banks and authorities to assess the resilience of individual banks and of the banking sector as a whole, especially since the

GFC.

Following the experience and lessons learned in the GFC, stress tests have become a common practice among authorities. Stress tests are exercises to assess the liquidity and solvency of a bank's portfolio under adverse scenarios. The scenarios considered in stress-test exercises must be severe, harsher than the market fluctuations than the bank usually faces, but believable. Stress-tets scenarios must be forward-looking and try to anticipate problems that the bank may face in the future.

Stress-tests were first used in a systematic way in the second half of the 1990s by the International Monetary Fund (IMF) and the World Bank starting in May 1999, in the context of the Financial Sector Assessment Program (FSAP) (see Baudino et al. (2018)). However, before the GFG, stress test played a secondary role in a portfolio of risk assessment techniques at the disposition of financial institutions (Blaschke et al. (2001) and Baudino et al. (2018)). For example, in the mid-2000s, the Basel II framework required banks to apply stress-test techniques for the assessment of the soundness of their portfolios, but the implementation in the subsequent years was not generalized and the models were in many cases not fully developed (BCBS (2009)).

However, the GFC changed the situation dramatically. First of all, the GFC displayed vividly that financial institutions and supervisors had failed to identify and comprehend the build-up of extreme levels of risk. In the second place, the GFG showed the consequences of badly managed risk and that problems in a particular asset class could cause massive damages to the global economy through different contagion channels. In this context, the financial institutions and the authorities renewed their interest in the possibilities of stress-test excises to restore market confidence in an environment where the resiliency of the entire system was in doubt. In the EU, systematic stress tests exercises are regularly conducted by the European Banking Authority (EBA).

Modern stress test frameworks are complex models. Typically stress test frameworks include a multitude of modules, each one modeling a particular feature of the financial system. Some of the most key aspects to be taken into account are the granularity of the input data, the risk coverage, risk definitions and modelization, interaction mechanisms and contagion paths.

4. The development of climate stress test frameworks

The major central banks in the world embarked in the late-2010s in the process of developing their frameworks to quantify and evaluate the resilience of their respective banking systems to climate risks. The process is likely to take many years before tested and comprehensive methodologies can be established.

For example, the ECB is currently developing an economy-wide climate stress test which they promise to be the most comprehensive exercise of its kind to date and take into account both transition and physical climate risks (de Guindos (2021)). It combines a detailed data-set of millions of NFC together with data on bank exposures and a set of climate and economic development scenarios. Concretely the exercise will encompass approximately four million companies worldwide and 2,000 banks – almost all monetary

financial institutions in the euro area – and will cover a period of 30 years into the future. This unprecedented data-set collects financial and climate information for millions of firms with information on both past and future firm-level emissions, accounting for firm-specific emission reduction targets under different scenarios. Particularly the carbon footprint of firms worldwide will be used to determine the potential impact of green policies. Also, a forward-looking physical risk score for each firm in the sample is created, which measures the future incidence of extreme natural phenomena as a result of climate change, such as riverside and coastal floods, wildfires, heat and water stress, and windstorms.

Preliminary outcomes of the ECB's new database show that the impact of climate risks on NFC exposures will likely be hugely heterogeneous across sectors and geographical areas. According to these early results, the biggest polluting firms will face transition risks the most, while areas most vulnerable to physical risk could face up to four times as much climate risk as the average firm over the next 30 years. Particularly, regarding climate risks, Southern European countries will be especially affected by extreme events such as heat stress and wildfires, while middle and northern European countries will be more exposed to flooding risk. The ECB considers that regarding transition risks, mining, energy, and manufacturing activities correspond to the most carbon-intensive sectors, and therefore are considered to be the more exposed to such risks (de Guindos (2021)). The vulnerable economic activities accounted for in this paper have been selected according to the early results of the ECB's stress test framework.

Some national Central Banks have moved ahead of the ECB's efforts and conducted and published results for climate stress tests exercises of financial institutions. For example, in France, a first voluntary pilot test was conducted in 2020 (see BdF (2020)). The exercise included nine banking groups and 15 insurance groups and considered physical and transition risks. The results show that even though France is relatively spared in the Intergovernmental Panel on Climate Change (IPCC) scenarios, the pilot exercise shows that the vulnerabilities associated with physical risk are far from negligible. One of the key results of the exercise is that most institutions found difficulties in constructing a comprehensive database for the assessment and analysis of the geographical distribution of their portfolio position. In BdF (2020), the central bank acknowledges that its climate stress framework is far from complete. Particularly the institution explains that the analysis does integrate sectoral interactions and the risk of a significant, if not massive, devaluation of the prices of certain assets, it does not take into account the risks of a spillover effect, of supply chain disruptions or of amplification that are typically observed during episodes of financial stress or crises.

The Bank of England (BoE), a pioneer institution in raising awareness of the significance of climate risks (see Carney (2015)), has announced that it will reveal the first results of its climate-stress framework in 2022. However, due to the experimental nature of the test, the BoE has announced that only aggregate, rather than firm-by-firm, results will be published. The BoE has confirmed that the exercise will focus on the credit risk embedded in the banks' balance sheet, with an emphasis on detailed analysis of risks to large corporate counterparties.

However, in the US, the FED has not officially announced the development of a climate stress test exercise. During November 2020 and just a few days after the return of

the country to the Paris Agreement, the Board of Governors of the Federal Reserve System recognized climate change as a systemic financial risk (see Board of Governors of the Federal Reserve System (2020)). In July 2021, Federal Reserve Chair Jerome Powell said the US central bank is considering the implementation of climate stress scenarios in the future.

The scientific literature on climate stress tests of the banking system is growing rapidly in recent years. For example, Battiston et al. (2017) developed a network-based climate stress-test methodology and applied it to large Euro Area banks in a 'green' and a 'brown' scenario. The authors of this study found that direct and indirect exposures to climate-policy-relevant sectors represent a large portion of investors' equity portfolios, especially for investment and pension funds. Additionally, Battiston et al. (2017) find that the portion of banks' loan portfolios exposed to these sectors is comparable to banks' capital. Furthermore, the results of this paper suggest that climate policy timing is key and that an early and stable policy framework entails smooth asset value adjustments and minimizes adverse systemic consequences that could come with abrupt policy changes. On the other hand, Battiston et al. (2019) discuss the challenge of selecting the relevant scenarios. Particularly the authors argue that the fundamental difficulty with assessing and managing climate-related financial risk comes from the fact that it is largely endogenous and involves multiple scenarios. To better operate in this framework, the authors argue in favor of combining the climate stress test approach with decision theory under uncertainty. Battiston et al. (2019) also acknowledge that one of the most pressing limitations that banks and supervisory institutions face is that data sources are limited and very fragmented. Actually, as discussed earlier, the ECB is in the initial stages of the development of its climate stress-tets framework and it is devoting most of its efforts to the development of a database collecting the main climate vulnerability of millions of firms. Developing databases for climate-related information is essential so the different players in the financial markets can assess, incorporate and price climate factors. With data for Mexican banks, Roncoroni et al. (2021) analyze the effects on the financial stability of the interplay between climate transition risk and market conditions, such as recovery rate and asset price volatility. Unlike the model that we present in this paper, Roncoroni et al. (2021) incorporate the role of investment funds, which are key players in the low carbon transition. The results of Roncoroni et al. (2021) show that in the event of a disorderly low-carbon transition, stronger market conditions allow reaching more ambitious climate policies at the same level of financial risk. Finally, Vermeulen et al. (2018) present a stress test analysis of the financial system in the Netherlands. The stress test results suggest that the losses for financial institutions in the event of a disruptive transition to a low carbon economy could be sizeable but also manageable. Individual financial institutions can improve their vulnerability to risks for their portfolio by adjusting their portfolio positions gradually in advance. In addition, policymakers can help to avoid unnecessary losses by implementing timely, reliable and effective climate policies.

5. Data

The stress test exercise performed in this article requires data on detailed exposures, capital and leverage figures at the bank level. Exposures must be differentiated between

liquid, illiquid and loans and advances to non-financial corporations (NFC). The exposures must also be disaggregated by country and exposures to NFC by country and economic activity. All data regarding the banks' balance sheets is retrieved from EBA databases,

- European Banking Authority 2018 EU-Wide Stress Tests. The exercise covers 70% of the EU banking sector and assess EU banks' ability to meet relevant supervisory capital ratios during an adverse economic shock. All data used in the stress exercise regarding the banks' balance sheet has been retrieved from this database with the exception of loans and advances to NFC by economic activity.

- European Banking Authority 2020 EU-Wide Transparency Exercise. The transparency exercise is part of the EBA's strategy to establish market discipline through transparency in the EU financial markets. The transparency exercise complements the banks' disclosure requirements under Basel III Pillar 3 and the EU's capital requirements directive (CRD). This database has provided the information necessary regarding the exposures to loans and advances to NFC by economic activity.

For each bank and with data from the EBA databases we have reconstructed the structure of the institution's portfolio. For the stress test model presented in this paper it is crucial to distinguish between interbank, iliquid and marketable (or marketable) asset classes. The table 1 states which asset classes have been considered and how they have been allocated across the three key cathegories.

Asset classes
Interbank
Credit instirutions
Illiquid assets
Loans to NFC
Residual exposures
Defaulted exposures
Indirect sovereign exposures in the trading book
Retail exposures
Commercial real estate exposure
Residential mortgage exposures
Liquid assets
Equity
Corporate bonds
Derivatives
Securitisation
Institutional client exposures: Central banks and central governments, Other financial corporations, Multilateral Development Banks, International Organisations Institutions and Public sector entities

Table 1: Classification of asset classes

Some of the scenarios considered in this stress test require information about exposures to loans and advances to NFC by country and industry. Unfortunately, in the database we only have information of exposures by country and sector of economic separately. This means, for example, that we know the exposure of each bank towards loans to Spanish firms and the position of each bank to firms in the water supply industry. However, we do not know the loans issued to Spanish firms in the water supply industry. To circumvent this limitation, we assume that at bank level the sector exposures are constant across countries. Being Υ_c the share of NFC loans value allocated to the country c and Υ_{cs} the share allocated to companies in sector s then the amount allocated to companies working in sector s and country c is

$$\Upsilon_{cd} = \Upsilon_c \Upsilon_s \tag{1}$$

Unfortunately, at bank level, if positions in a sector are concentrated in a particular country, we will not be able to detect it. A second limitation of our database is that we do not have information on exposures with detailed sector classification within manufacturing. Since different manufacturing industries will have very different levels of exposure to climate risks is essential to have greater detail in the data on exposures within manufacturing. For example, in this paper we assess the resilience of the banking sector to a significant disruption in the manufacturing of road transport equipment. To calculate a bank's position

in a particular industry within manufacturing, we use the industry's share in manufacturing GDP for each particular country. Unfortunately, if an industry has a larger debt level to GDP in relation to its manufacturing peers, we will not be able to detect it.

Data is also necessary to estimate the market depth of marketable asset classes. Market depth is required to simulate the impact of fire sales on the securities market price. We calculate market depth we use data from two different sources. First, we estimate volatility parameters σ_u using daily returns of S&P sector indices. Second, we obtain average daily volume estimates ADV_q from annual volume data provided by the US Treasury and various central banks.

6. Creation of a network of inter-bank position

In this section we show how to construct a matrix of inter-bank exposures from the data released in the EBA Stress-test exercises. In the EBA 2028 EU-wide stress test exercise databases, we have information on the value amount of assets and liabilities that each bank has in the balance sheet with other credit institutions as counterparties. However, we do not have data on the individual banks that are behind such aggregate positions. This is to say that we know how much each bank owes and is owed in the inter-bank market, but we do not have the complete inner structure of the inter-bank network.

Next, we outline the estimation procedure adopted to circumvent this limitation. Particularly, we use a fitness model technique that has been used to reconstruct financial networks starting from aggregate exposures (Musmeci et al. (2013); Montagna and Lux (2017) among others).

When reconstructing the inter-bank network, we consider x_b as the aggregate amount of inter-bank assets in the balance sheet of bank b. On the other hand, y_v is the aggregate amount of inter-bank liabilities in the balance sheet of bank v. Now, we can estimate the probability that a bank b lends funds to bank v as

$$p_{bv} = \frac{z x_b y_v}{1 + z x_b y_v} \tag{2}$$

where z is a free parameter. z sets network density and set considering empirical evidence on the density of different inter-bank networks (see Veld and van Lelyveld (2014)) to 5%.

Finally, in order to generate an inter-bank network, we now combine two different sources of information. Concretely we randomize an inter-bank network by drawing 100 structures from the set of $B * B$ probabilities p_{bv} while imposing the fundamental constraint that the sum of bank to bank inter-bank asset exposures x_{bv} equals for each bank its total inter-bank asset position x_b and liabilities y_b. To do so, we use an iterative proportional fitting algorithm. The iterative proportional fitting algorithm finds the fitted matrix, which is the most similar to an original matrix but whose row and column are equivalent to those of another matrix.

7. Scenarios

In this stress test exercise, we consider the physical and transition risks associated with climate change.

7.1. Phisical risks

Physical risks are the risks associated with the effects of climate change upon economic activity and assets. They may include impacts on water availability, sourcing, and quality, food security. Also, physical risks include the impacts of extreme weather events such as torrential rains, flooding, extreme temperatures and increasing firestorms. Likewise, they include the financial impacts of the legislative and regulatory reforms that arise from these hazards. The scenarios considered in this stress test exercise have been selected from the conclusions for Europe of the Assessment of Impacts, Adaptation, and Vulnerability contribution to the IPCC's Fifth Assessment Report (WGII AR5) and the early results of the ECB's climate stress test framework (see de Guindos (2021)).

We consider impacts on the exposures to:

- Agriculture, forestry and fishing, particularly in southern Europe.
- Agriculture, forestry and fishing, all positions.
- Water supply, particularly in southern Europe.
- Water supply, all positions..
- Accommodation and food service activities, particularly in southern Europe.
- Construction and real state services, all positions.

7.2. Transition risks

Transition risks are the risks related to the process of adjustment towards a low-carbon economy (see ECB(2020) and Bank for International Settlements (2021)). They can arise through changes in public sector policies, innovation and changes in the affordability of existing technologies, or investor and consumer sentiment towards a greener environment.

A smooth low-carbon transition occurs when the different firms, households and individuals are given clear and stable incentives and enough time to adapt to the future green economy. Hence a smooth transition offers a path for technological progress to deliver cost-effective solutions for the challenges of climate change. Additionally, a smooth transition must maintain energy prices under control so the viability of significant economic activities is not persistently threatened. A stable regulatory framework delivers a long term path to gradually phase-out capital stocks linked with fossil energies and minimizes the possibility of sudden and massive fluctuation in the price of energy related assets. Hence the stability of bank credit positions and investment portfolios will be enhanced. Finally, the new investments required in greener and newer technologies will offer new opportunities for the economy.

On the other hand, a disorderly transition would entail, for example, unaffordable spikes in energy prices, limitations in the energy supply and sharp change in the valuation of fossil fuel related capital stocks. Banks' credit position would be threatened by bad investments and the sharp downward revaluation of carbon-intensive firms (see(Nieto(2017))).

Following the ECB's working progress framework (see de Guindos (2021)), we characterize the exposure of the different sectors to transition risks according to their level of emissions. We implement two different scenarios of this kind, a first scenario weighting the sector level transition impacts with direct sector emissions and a second one using embeded emissions in the sectors GVC.

Firstly, if E_i are the GHG emissions released by sector i, the probability of loan default in the sector i $\bar{\pi}_i$ will be defined by the share of the sector emissions on overall emissions as $\pi_i = \frac{E_i}{\sum_j^N E_j}\hat{\pi}$, where .

Secondly, we defined a transition scenario based on embedded emissions in the GvC. Embeded emissions represent the carbon footprint calculated through a sectors entire supply chain. Being $\bar{E}_i$ the embedded emissions for sector i, E_i the emissions released by the same sector and w_{ij} the share of i's sales devoted to purchasing input j, embedded emissions are defined as $\bar{E}_i = E_i + \sum_j^N w_{ij}\bar{E}_i$. Embedded emission for the entire productive structure can be defined in matrix form as:

$$\bar{E} = E + W\bar{E} \tag{3}$$

with the different vectors and matrices being defined as:

$$W\bar{E} = \begin{pmatrix} w_{1,1} & w_{2,1} & \cdots & w_{n,1} \\ w_{1,2} & w_{2,2} & \cdots & w_{n,2} \\ \vdots & \vdots & \ddots & \vdots \\ w_{1,n} & w_{2,n} & \cdots & w_{n,n} \end{pmatrix} \begin{pmatrix} \bar{E}_1 \\ \vdots \\ \bar{E}_n \end{pmatrix}, \bar{E} = \begin{pmatrix} \bar{E}_1 \\ \vdots \\ \bar{E}_n \end{pmatrix}, E = \begin{pmatrix} E_1 \\ \vdots \\ E_n \end{pmatrix} \tag{4}$$

The system on N equations defined by 4, can be rewritten as $\bar{E} = (I - W)^{(-1)}E = LE$. The Leontief matrix L, captures the embedded emissions in the sectors i production through all possible combinations in the value chain. Again, the Leontief matrix L can be decomposed into $L = I + W + W^2 + ... + +W^\infty$. Again, if π_i is the probability of loan failure in sector i, $\pi_i = \frac{\bar{E}_i}{\sum_j^N \bar{E}_j}\hat{\pi}$ of the positions in NFC loans towards sector i.

Also, as sector level shocks we consider impacts on the exposures to:

- Mining and quarrying.
- Electricity, gas, steam and air conditioning supply.
- Manufacturing of road transport equipment.
- Manufacturing.
- Transport and storage.

8. Model

In this section we present a climate stress test methodology that includes contagion through the real economy, and direct and indirect contagion through the financial system. Concretely we focus on the impacts arising from losses in loans to non-financial corporations. In this model we are going to define the dimensions of interaction that foster contagion and may allow to systemic crisis arise from relatively minor shocks.

At any moment the balance sheet of the banking institution b must satisfy the following equality

$$\epsilon_b^t + D_b^t + \sum_v^B \Phi_{vb}^t{}' + O_b^t = \sum_v^B \Phi_{bv}^t + \sum_q^Q \Psi_{bq}^t + I_b^t + \sum_i^N I_{bi}^{NFCt} \tag{5}$$

On the left site of the balance sheet equilibrium equation of bank b at time t, ϵ_b^t is the equity, D_b^t the value of the deposits, Φ_{bv}^t the money borrowed from bank v and O_b^t are other sources of financing. On the right side, Φ_{bv}^t represents the money owed by bank v to bank b, Ψ_{bq}^t the amount of marketable security q, I_{bi}^{NFCt} the loans issued do NFC in sector i and I_b^t the total value of other iliquid assets, in the balance sheet of bank b. There are B banking institutions, Q marketable asset classes and N different economic activities in the real economy.

The balance sheet of the banking sector can be defined in a concise matrix expression. For the B banks in the banking system, the equality of the balance sheet is

$$\epsilon^t + D^t + \Phi^{t\prime} 1_{B*1} + O^t = \Phi^t 1_{B*1} + \Psi^t 1_{Q*1} + I^t + I^{NFCt} 1_{n*1} \tag{6}$$

where ϵ^t, D^t, and I^t are vectors of dimension $Bx1$ containing respectively the equity, deposits, total iliquid assets respectively in the balance sheet of each bank at time t.

$$\epsilon^t = \begin{pmatrix} \epsilon_1^t \\ \vdots \\ \epsilon_B^t \end{pmatrix}, D^t = \begin{pmatrix} D_1^t \\ \vdots \\ D_B^t \end{pmatrix}, \Psi^t = \begin{pmatrix} \Psi_1^t \\ \vdots \\ \Psi_B^t \end{pmatrix}, I^t = \begin{pmatrix} I_1^t \\ \vdots \\ I_B^t \end{pmatrix}, I^{NFC^t} = \begin{pmatrix} I_1^{NFC^t} \\ \vdots \\ I_B^{NFC^t} \end{pmatrix} \tag{7}$$

Also 1_{B*1}, $1_{Q*1}4$, 1_{n*1} are unit vectors of the indicated length. The matrix Φ^t is a matrix of dimensions $B*B$ that states the inter-bank positions across banks. Similarly, the matrix Ψ^t of dimensions $B*Q$ indicates the amount of each marketable security that each bank owns. Finally, I^{NFCt} is a matrix of dimension $B*n$ that states the amount that each bank has lent to NFC from each economic activity.

$$\Phi^t = \begin{pmatrix} 0 & \Phi_{1,2}^t & \cdots & \Phi_{1,B}^t \\ \Phi_{2,1}^t & 0 & \cdots & \Phi_{2,B}^t \\ \vdots & \vdots & \ddots & \vdots \\ \Phi^t w_{B,1} & \Phi_{B,2}^t & \cdots & 0 \end{pmatrix} \tag{8}$$

$$\Psi^t = \begin{pmatrix} \Psi^t_{1,1} & \Psi^t_{1,2} & \cdots & \Psi^t_{1,Q} \\ \Psi^t_{2,1} & \Psi^t_{2,2} & \cdots & \Psi^t_{2,Q} \\ \vdots & \vdots & \ddots & \vdots \\ \Psi^t_{B,1} & \Psi^t_{B,2} & \cdots & \Psi^t_{B,Q} \end{pmatrix}, I^{NFCt} = \begin{pmatrix} I^{NFCt}_{1,1} & I^{NFCt}_{1,2} & \cdots & I^{NFCt}_{1,n} \\ I^{NFCt}_{2,1} & I^{NFCt}_{2,2} & \cdots & I^{NFCt}_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ I^{NFCt}_{B,1} & I^{NFCt}_{B,2} & \cdots & I^{NFCt}_{B,n} \end{pmatrix} \tag{9}$$

In this context the leverage ratio of bank b at time t, Γ^t_b is

$$\Gamma^t_b = \frac{\sum_v^B \Phi^t_{bv} + \sum_q^Q \Psi^t_{bq} + I^t_b + \sum_i^N I^{NFCt}_{bi}}{\epsilon_b} \tag{10}$$

As a departing point, the losses suffered by the portfolio of a given bank b at period t in its position of loans to NFC is defined as:

$$\Pi^t_b = \rho \sum_i^N \bar{\pi}^t_i I^{NFC^{t-1}}_{bi} \tag{11}$$

where $\bar{\pi}_i$ is the probability of loan default in the sector i, I^{NFC}_{bi} the exposure of bank b to loans to sector i and ρ is a parameter that indicates the loss given default and takes values in the range [0,1]. Physical and transition risks will be translated into higher default probabilities π_s for the relevant sectors.

The first layer of contagion we introduce is the contagion within the real economy. Contagion in the real economy will exist if the probability of default in sector i is characterized by the probability of default in other sectors and a structure of contagion ($\widetilde{W}$).

$$\bar{\pi}^t_i = f(\bar{\pi}^t_1, ..., \bar{\pi}^t_n, \widetilde{W}^t). \tag{12}$$

The study of contagion within the real economy has been well studied in the literature from a theoretical an empirical perspectives and for different contagion channels. One of the key contagion channels in the real economy is the production network. Contagion through the production chain occurs when not payed bills by failing companies are transmit through successive rounds of suppliers.

The phenomena of cascading failures in the production structure is studied theoretically in Baqaee (2018). Using a model in general equilibrium an featuring an input-output structure together with imperfect competition and external economies of scale shows that the strucure of the supply chain can amplify of shocks, generating cascades of firm entry and exit across the economy. Empirical work on this front includes Foerster et al.(2011), Di Giovanni et al. (2014), Atalay (2017), and Acemoglu et al. (2016).

$\bar{\pi}_i{}^t$ is the final probability of default at sector i after taking into consideration the other sectors' performance, π^t_i is the idiosyncratic probability of default of the same sector and $\widetilde{w}^t_{ij}$ the share of i's sales bought by j. For simplicity, we assume linear contagion between sectors. Hence,

$$\bar{\pi}_i{}^t = \pi^t_i + \sum_j^N \widetilde{w}^t_{ij} \bar{\pi}_j{}^t \tag{13}$$

which can be expressed in matrix form as

$$\bar{\pi} = \pi^t + \widetilde{W}^t \bar{\pi}^t \tag{14}$$

with the corresponding vectors and matrices being defined as:

$$\widetilde{W}\bar{\pi} = \begin{pmatrix} w_{1,1} & w_{2,1} & \cdots & w_{n,1} \\ w_{1,2} & w_{2,2} & \cdots & w_{n,2} \\ \vdots & \vdots & \ddots & \vdots \\ w_{1,n} & w_{2,n} & \cdots & w_{n,n} \end{pmatrix} \begin{pmatrix} \bar{\pi}_1 \\ \vdots \\ \bar{\pi}_n \end{pmatrix}, \bar{\pi} = \begin{pmatrix} \bar{\pi}_1 \\ \vdots \\ \bar{\pi}_n \end{pmatrix}, \pi = \begin{pmatrix} \pi_1 \\ \vdots \\ \pi_n \end{pmatrix} \tag{15}$$

rearranging 14 to $\bar{\pi}^t = (I - \widetilde{W}^t)^{(-1)}\pi = \widetilde{L}^t \pi^t$ the losses suffered by the portfolio of a given bank b at tiem t are characterized. Hence, departing from a vector of idiosyncratic probabilities of failure π^t losses in the loan to NFC positions are

$$\Pi^t = \rho I^{NFCt-1} \widetilde{L}^t \pi^t \tag{16}$$

and for bank b

$$\Pi_b^t = \rho \sum_i^N \sum_j^N \widetilde{l}_{ij}^t \pi_j^t I_{bi}^{NFCt-1} \tag{17}$$

where $\widetilde{L}^t = (I - \widetilde{W}^t)^{(-1)}$ is the $N * N$ matrix that characterizes contagion through the global production chain and synthesizes the full structure of contagion through infinite routes of interaction and can be approximated as $L = I + W + W^2 + ... + W^\infty$.

Similarly, the portfolio for bank b of loans to NFC of sector i evolves as:

$$I_{bi}^{NFCt} = (1 - \rho)\widetilde{l_{ij}}^t \pi_j^t I_{bi}^{NFCt-1} \tag{18}$$

Now we consider a second source of contagion, indirect contagion through market losses arising from fire sales. Indirect contagion arises from pro-cyclical feedback effects since fire sales of assets due to deleveraging can further depreciate asset prices and lead to losses in other portfolios, generating endogenous instability.

16 characterizes losses at bank level. To cover the losses and reestablish the leverage ratio the bank sells marketable assets. Since banks have large portfolios, fire sales can trigger price drops that further degrade the state of the banks portfolio. At the initial stage, capital is impacted by losses.

$$\epsilon_b^t = \epsilon_b^{t-1} - \Pi_b^t \tag{19}$$

Henceforth the leverage ratio of bank b at time t,

$$\Gamma_b^t = \frac{\sum_v^B \Phi_{bv}^t + \sum_q^Q \Psi_{bq}^t + I_b^t + \sum_i^N I_{bi}^{NFCt}}{\epsilon_b^{t-1} - \Pi_b^t} \tag{20}$$

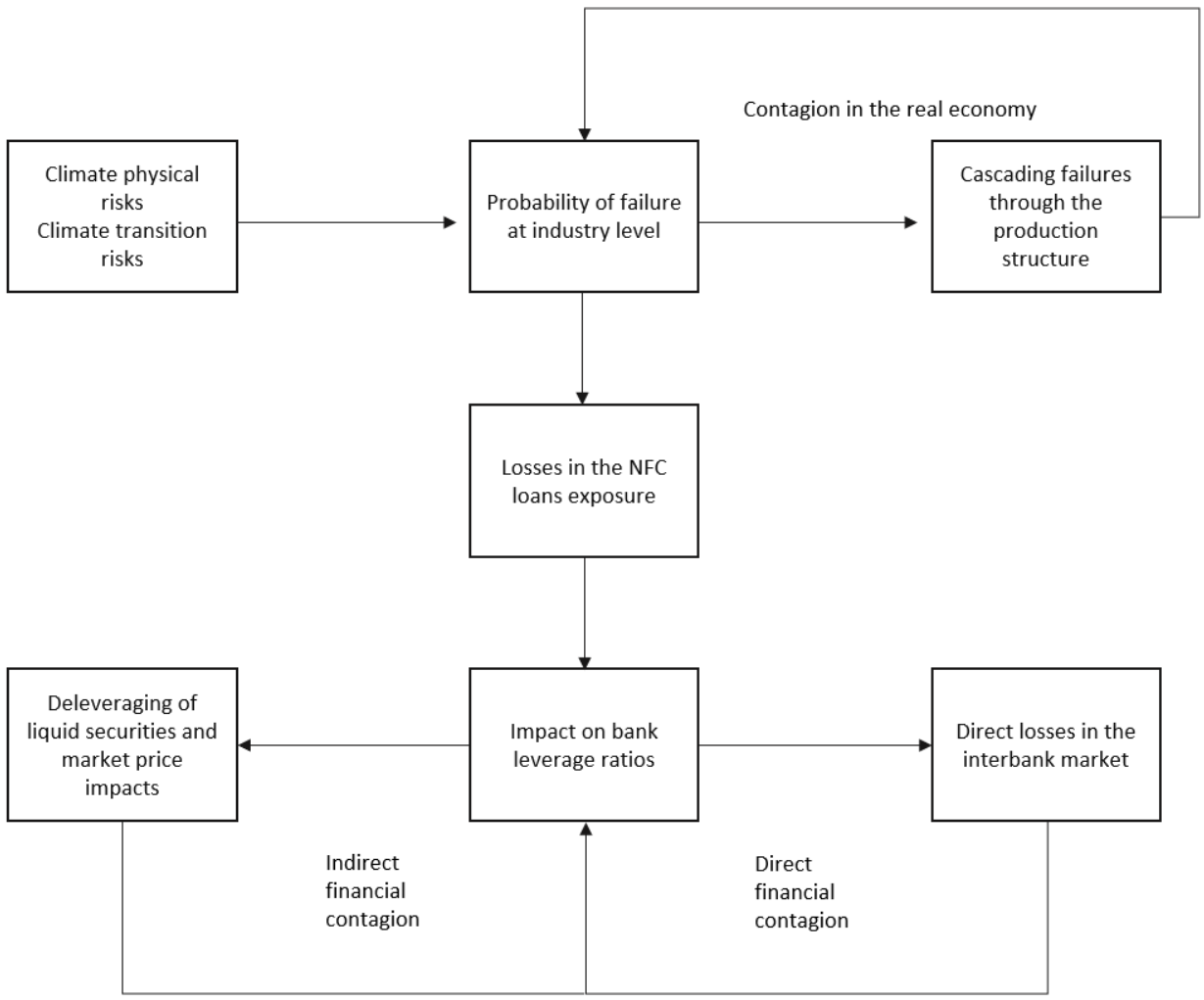

Figure 1: Sector policy in context

I introduce two additional assumptions. First deleveraging does not start until the leverage (Γ_b^t) ratio has not cross a critical level (Γ_b^{limt}). Secondly, when the bank deleverages aims at an objective leverage ratio (Γ_b^{objt}).

The fire sales mechanics follow those proposed by Cont and Schaanning (2017). The ratio of deleveraged assets is characterized by the ratio between the amount funds requirements (characterized by the level of capital and the difference between the actual leverage and the objective) and the existing aggregate position of marketable assets. Leverage will only occur if leverage falls below the objective. Hence the share of marketable assets that bank b will deleverage is equal to:

$$\Lambda_b^t = \frac{\epsilon(\Gamma_b^t - \Gamma_b^{objt})}{\Psi_b^t} \mid \Gamma_{bt}^t > \Gamma_{bt}^{limt} \tag{21}$$

where $\Psi_b^t = \sum_1^Q \Psi_{bq}^t$ is the total amount of marketable securities in the portfolio of

bank b. All marketable securities in the portfolio of a bank will be deleveraged in the same proportion.

In absolute terms, the amount deleveraged by marketable asset class D_q is characterized at bank level by the share of marketable assets deleveraged and the structure of marketable positions.

$$D_q^t = \sum_b^B \Lambda_b^t \Psi_{bq}^t \tag{22}$$

Each institution b deleverages by selling a proportion Λ_b of its marketable assets, leading to an aggregate amount D_q^t of sales for each particular asset class q at time t. The market impact of asset sales result in a decline in market prices. This decline in asset prices will impact the portfolio value of all the banks in the system. The loss due indirect contagion through market losses is characterized by price impacts that are a product of the amount subject to fire sales in relationship of the market depth $\binom{t}{q}$for the particular security. We used the exponential function proposed in Cifuentes et al. (2005).

$$\Delta p_{qt} = 1 - exp(-\frac{D_q^t}{M_q^t}) \tag{23}$$

The transmissions of shocks through price adjustments from portfolio b to bank portfolio u depends on the liquidity weighted overlap between portfolio b and u ($\Theta_{bu} = \sum_1^N \frac{\Psi_{bq}\Psi_{uq}}{M_q}$). The structure of the overlapping portfolios for the entirety of the banking system defines the network of indirect contagion.

Market depth of security q, M_q describes a market's capacity to maintain relatively large market orders without much affecting the price of the security and security.

We note that both trading volume and volatility are associated with a liquidation horizon τ. Most studies assume a daily liquidation horizon. If we assume the liquidation horizon τ to be longer than a day, then the market depth parameter needs to be adjusted. Market depth is:

$$M_q = c\frac{ADV_q\tau}{\sigma_q\sqrt{\tau}} \tag{24}$$

Where c is a coefficient close to 0.5, ADV_q is the daily average trading volume in the market for security b and σ_q is the volatility of daily price for asset q. τ is the time liquidation horizon in days. This adjustment is important, and corresponds to the intuitive observation that liquidating the same portfolio over a longer horizon reduces impact. The liquidation horizon τ may be interpreted as the time window the banks dispose of to comply with portfolio constraints. In the case study below we will use $\tau = 31$ days.

As in Cont and Schaanning (2017), the portfolio of marketable positions will evolve according to the amount of securities sold and the evolution of its price

$$\Psi_{bq}^{t+1} = (1 - \Lambda_b)\Psi_{bq}^t(1 - \Delta P(D_q(\gamma \sum_i^N {}^t \sum_j^N \widetilde{l}_{ij}^t \pi_j^t I_{bi}^{NFCt-1}))) \tag{25}$$

Hence, 26 shows the price adjustment triggered by the deleveraging port

Similarly to Cont and Schaanning (2017), the losses incurred in the deleveraging process are defined as

$$\Pi_{M_q}^t = (1-(1-\alpha)\Lambda_b)\sum_b^B\sum_q^Q \Psi_{bq}^t(\Delta P(D_q(\gamma\sum_i^N{}^t\sum_j^N \widetilde{l}_{ij}^t\pi_j^t I_{bi}^{NFCt-1}))) \tag{26}$$

$(\Delta P(D_q))$ defines the price impact while $(1-(1-\alpha)\Lambda)$ can be separated in $(1-\Lambda)$ standing for full price impact on the non sold securities and $(1+\alpha\Lambda)$ standing for $\alpha\%$ price impact of on the sold securities. This latter component accounts for the fact that a part of securities sold will be affected by the price drop.

Finally, we define inter-bank contagion from the basic structure of a balance sheet.

$$\epsilon^t + D^t + \Phi^{t\prime}1_{B*1} + O^t = \Phi^t 1_{B*1} + \Psi^t 1_{Q*1} + I^t + I^{NFCt}1_{n*1} \tag{27}$$

If Σ^t is the vector that contains the aggregate measure of total assets or liabilities, $\bar{\Sigma}^t$ is a diagonal matrix such that Σ^t=$\bar{\Sigma}^t 1_{B*1}$ and $\Xi^t = \Phi^t\bar{\Sigma}^{(-1)}$, 27 can be rearranged following $\Sigma^t = \Phi^t\bar{\Sigma}^{t-1}\bar{\Sigma}^t 1_{B*1} + \Psi^t 1_{Q*1} + I^t + I^{NFCt}1_{n*1} = \Xi^t\Sigma^t + \Psi^t 1_{Q*1} + I^t + I^{NFCt}1_{n*1}$ to

$$\Sigma = (I-\Xi^t)^{-1}(\Psi^t 1_{Q*1} + I^t + I^{NFCt}1_{n*1}) \tag{28}$$

with Ξ^t being $\Phi^t\bar{\Sigma}^{(-1)}$ and $(I-\Xi^t)^{-1}$ the BxB matrix that characterizes contagion through the interbank market. $(I-\Xi^t)^{-1}$ encapsulates the full structure of contagion through infinite routes of interaction since it is equivalent to $(I+\Xi^t+\Xi^{t2}+...+\Xi^{t\infty})$. Combining expressions 28 and 16

$$L = (I-\Xi^t)^{-1}(1-(1-\alpha)\Lambda_b)\sum_b^B\sum_q^Q \Psi_{bq}^t(\Delta P(D_q(\gamma\sum_i^N{}^t\sum_j^N \widetilde{l}_{ij}^t\pi_j^t I_{bi}^{NFCt-1}))) \tag{29}$$

As a result, there is a potential systemic risk that can materialize through direct successive-round effects. Counterparty risk may occur through balance sheet contagion when the default of one institution may lead to write downs of assets held by its counterparties which may result in their insolvency. However, more generally, the accounting practice of mark-to-market implies that the deterioration of the balance sheet of a financial institution has a negative impact on the market value of its obligations held by its counterparties. Hence, the inter-bank exposure to a climate-policy-relevant sector along chains of financial actors is determined by the product of the face value of the exposures along the chain. Therefore, the problem of identifying relevant indirect exposure of an infinite path length is mathematically equivalent to the graph-theoretical problem of finding the path(s) with the largest product of link weights along the path in a weighted graph (see Battison et al. (2017)). Mark-to-market and, in particular, credit valuation adjustment, is recognized as a major mechanism of financial distress propagation; during the 2007/2008 financial crisis, it accounted for two-thirds of losses among many financial institutions (see FSA (2010)).

9. Results

In this section, we discuss the results of the stress test exercise. First, we discuss the current state of the banks' balance sheets. Later we discuss the results of the stress test exercise.

The stress test methodology presented in this paper focuses on impacts on the bank's positions in loans issued to NFC. Figure 3 shows the current ratio of non-performing loans (NPL) for different counterparties. The data shows that NPL ratios vary massively between large corporations and SMEs. Loans to SMEs have the highest NPL ratio among all the counterparties (18.5% in 2015 and 8.5% in 2019). On the other hand, loans to large corporations have among the lowest ratios of NPL (4.6% and 2.1% respectively). This means that in countries where the productive structure is dominated by SMEs (like is the case of countries such as Spain), the banking system may be more exposed to shocks. Figure 3 also shows that NPL ratios have sharply fallen in the years following the end of the financial and euro crisis. It is important to consider that a NPL does not translate into a total loss in the position at bank's balance sheet. This fact is accounted for in the model by the parameter ρ, that we have set as $\rho = 1$ in order to facilitate the interpretation of the results.

Figure 4 shows the 2019 NPL ratios for NFC by economic activities. The data shows that the ratios are very heterogeneous across economic activities. For example, construction loans have the highest ratios of NPL (14.9%), while public administration loans are the lowest (1.2%). Among the sectors considered in the analysis of climate and transition risks, some industries like electricity, gas, steam and air conditioning supply together with water supply have very low rates (2,8% and 3%). Others like manufacturing, mining, transport and agriculture, forestry, and fishing are at medium levels (5.7%, 6.5%, 7% and 7.4%). With a high ratio but below construction, we find accommodation and food service activities (9.2%).

Figure 5 shows the capital ratios for the different banks in the dataset. The data shows that the capital ratios are very heterogeneous, ranging from 12% to less than 4%. This means that there are banks much more prepared than others to absorb losses. Finally figures 6 and 7 show the size and composition of the balance sheet of the banks in the database. Again, the data shows that the structure is quite diverse. By the design of the stress-test performed, banks whose business relies more on serving NFC (instead of households or other financial institutions, for example) will be more harshly impacted by the climate and transition scenarios considered. However it is important to take into account that in the presence of contagion the losses may become widespread.

The results of the stress test show that if climate change economic risks and the transition to a low carbon economy economic risk in Europe are localized, they are not likely to cause a banking systemic crisis due to the initial asset valuation deterioration (see Table 2).

Particularly if we focus only on the initial direct losses (see Table 2) the impact of climate risks is generally small. For example, except for construction, none of the sector-specific shocks generate a bank failure with a 25% loss. With losses from 50% and above, impacts on manufacturing and electricity, steam and air conditioning supply generate a few bank bankruptcies, although not a wide-system failure. It is important to take into account

that such big shocks are not likely unless a truly catastrophic event develops.

Direct impacts losses only generate significant banking crises if the impacts are generalized across the economy. However, the results change significantly when we consider the different layers of contagion (see Table 3). First, the results show that an impact on water supply industry will not be significant enough to generate bank bankruptcies. This is to say that even if we impose a 100% loss in these positions, banks can absorb the impact, even in the presence of contagion. These results indicate that the banking system is very resilient to impacts in the water supply industry mainly because the overall exposure to the sector is small. The same can be said when banks are forced to write off their positions in the agriculture, forestry and fishing industries. Impacts to the activity in southern Europe are unable to deliver a single bank failure. However big impacts to the global positions in the sector generate the bankruptcy of a third of the banks. However, such an adverse impact in the agriculture, forestry and fishing industry at a global scale would imply a cataclysmic climatic event. Some scenarios regarding transmission risks also deliver a stable banking system. For example, the results show that the banking system is able to absorb the complete depletion of the positions in the mining and quarrying industries. On the other hand, in the presence of the three contagion channels considered, a loss in the road vehicle manufacturing industry may generate losses that cause around a third of the institutions to go bankrupt. However, the required initial impacts are very high and therefore, much less likely.

However, the results suggest that the banking system is fragile to impacts upon several key economic activities. Particularly problems in banking positions to overall manufacturing, transport, and storage and particularly construction and real estate activities are able to generate significant banking crises with impacts below 25% of the initial positions. A crisis in construction and real estate activities causes the bankruptcy of half of the systemic European banks with only a 25% position loss in the sector. Without contagion, the losses are much more limited although a few banking failures are possible even for plausible scenarios. This is an indication of the dangerous connection between problems in the construction sector and instability in the banking system. This shows that extreme climate events may be able to generate bank bankruptcies through losses in the construction industry. If these losses are above 15% to 20% of all positions, (which is less likely because of the geographic dispersion of construction counterparties) the instability in the banking system can reach a system-wide failure situation.

The scenarios where all the considered sectors are hit simultaneously (and therefore are less likely) deliver mixed results. The southern Europe scenario that considers agriculture, forestry and fishing, water supply, and accommodation and food service activities in southern Europe does not represent a significant risk for the financial sector.

On the other hand, the combined transition risks scenario featuring losses in manufacturing, mining, and quarrying, electricity, steam and air conditioning supply and transport and storage show significant financial risks. Finally, the general physical risks scenario is mainly driven by the impacts on construction activities.

10. Conclusion

The aim of this paper is to test if the European banking sector is resilient to losses in loans to economic activities exposed to climate risks or the energy transition. This paper presents a banking stress test methodology for European banks, focusing on loan exposures to economic activities likely to be impacted by the risks associated with climate change and the energy transition. First a network of contagion through the real economy is used incorporating the structure of the global production chain; secondly two network mechanisms of financial contagion are considered: indirect contagion through adjustments in the price of assets and direct contagion in the inter-bank market. This research project combines data from ordinary stress test exercises carried out by the European Banking Authority at the end of 2018 with new data by the same institution on sector level exposures. An inter-bank network is extrapolated from bank stress data by using a process of total exposure re-balancing, exposure link assignment and exposure volume allocation through a proportional fitting algorithm. The results of the stress tests show that when direct and indirect contagion are allowed a crisis in the European banks is possible, especially if industrial sectors such as manufacturing and construction industries are hit.

Since climate risks are relevant, they should be introduced in policymaking. Tougher capital requirements must be placed towards banks more exposed to climate and transition risks. Besides reinforcing the stability of the system, such a policy will place incentives to manage with more attention assets more exposed to climate and transition risky assets. Equally, when facing of contagion, the policy implications are clear. Tougher capital requirements should be placed to those banks central to the direct and indirect contagion paths for climate and transition risks.

11. Appendix

11.1. Figures and tables

Lei_code	Country	Bank_name
2138005O9XJIJN4JPN90	GB	The Royal Bank of Scotland Group Plc
213800X3Q9LSAKRUWY91	BE	KBC Group NV
2W8N8UU78PMDQKZENC08	IT	Intesa Sanpaolo S.p.A.
3M5E1GQGKL17HI6CPN30	DK	Jyske Bank
529900HNOAA1KXQJUQ27	DE	DZ BANK AG Deutsche Zentral-Genossenschaftsbank
529900W3MOO00A18X956	HU	OTP Bank Nyrt.
5493000LKS7B3UTF7H35	PL	Bank Polska Kasa Opieki SA
5493006QMFDDMYWIAM13	ES	Banco Santander S.A.
549300GKFG0RYRRQ1414	NO	DNB Bank Group
549300NYKK9MWM7GGW15	NL	ING Groep N.V.
549300PPXHEU2JF0AM85	GB	Lloyds Banking Group Plc
549300TRUWO2CD2G5692	IT	UniCredit S.p.A.
635400AKJBGNS5WNQL34	IE	Allied Irish Banks Group plc
635400C8EK6DRI12LJ39	IE	Bank of Ireland Group plc
7437003B5WFBOIEFY714	FI	OP Financial Group
7CUNS533WID6K7DGFI87	ES	CaixaBank, S.A.
7LTWFZYICNSX8D621K86	DE	Deutsche Bank AG
81560097964CBDAED282	IT	Unione di Banche Italiane Società Per Azioni
815600E4E6DCD2D25E30	IT	Banco BPM S.p.A.
851WYGNLUQLFZBSYGB56	DE	Commerzbank AG
9695000CG7B84NLR5984	FR	Group Crédit Mutuel
96950066U5XAAIRCPA78	FR	La Banque Postale
9ZHRYM6F437SQJ6OUG95	AT	Raiffeisen Bank International AG
A5GWLFH3KM7YV2SFQL84	BE	Belfius Banque SA
B81CK4ESI35472RHJ606	DE	Landesbank Baden-Württemberg
DIZES5CFO5K3I5R58746	DE	Landesbank Hessen-Thüringen Girozentrale AdöR
DSNHHQ2B9X5N6OUJ1236	DE	Norddeutsche Landesbank - Girozentrale -
F3JS33DEI6XQ4ZBPTN86	SE	Skandinaviska Enskilda Banken - group
FR9695005MSX1OYEMGDF	FR	Groupe BPCE
FR969500TJ5KRTCJQWXH	FR	Groupe Crédit Agricole
G5GSEF7VJP5I7OUK5573	GB	Barclays Plc
K8MS7FD7N5Z2WQ51AZ71	ES	Banco Bilbao Vizcaya Argentaria S.A.
LIU16F6VZJSD6UKHD557	DK	Nykredit Realkredit
M312WZV08Y7LYUC71685	SE	Swedbank - group
MAES062Z21O4RZ2U7M96	DK	Danske Bank
MLU0ZO3ML4LN2LL2TL39	GB	HSBC Holdings Plc
NHBDILHZTYCNBV5UYZ31	SE	Svenska Handelsbanken - group
O2RNE8IBXP4R0TD8PU41	FR	Société Générale S.A.
P4GTT6GF1W40CVIMFR43	PL	Powszechna Kasa Oszczednosci Bank Polski SA
PQOH26KWDF7CG10L6792	AT	Erste Group Bank AG
R0MUWSFPU8MPRO8K5P83	FR	BNP Paribas
SI5RG2M0WQQLZCXKRM20	ES	Banco de Sabadell S.A.
VDYMYTQGZZ6DU0912C88	DE	Bayerische Landesbank

Figure 2: List of bank entities

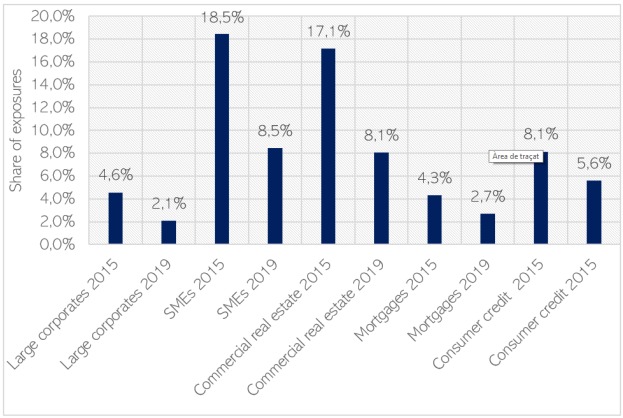

Figure 3: NPL ratio by counter-party for European banks.

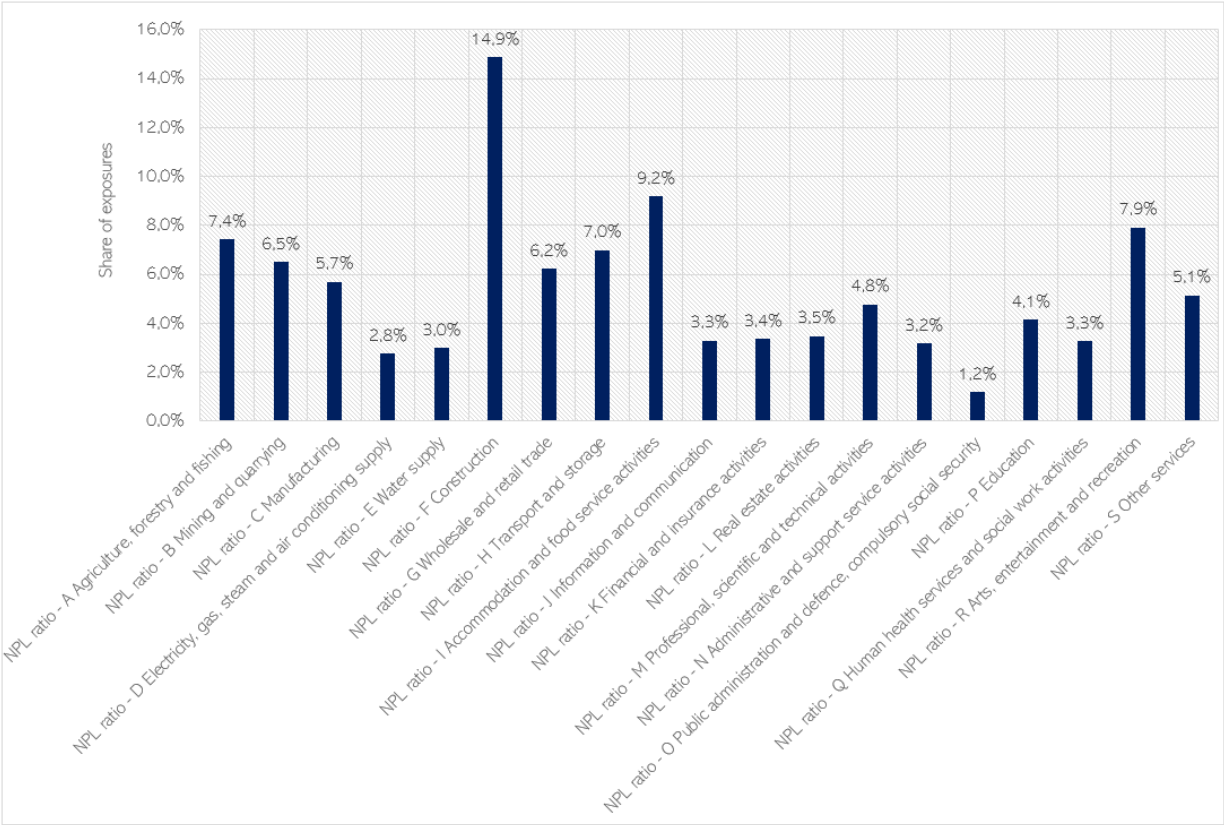

Figure 4: NPL ratio to NFC by economic activity for European banks.

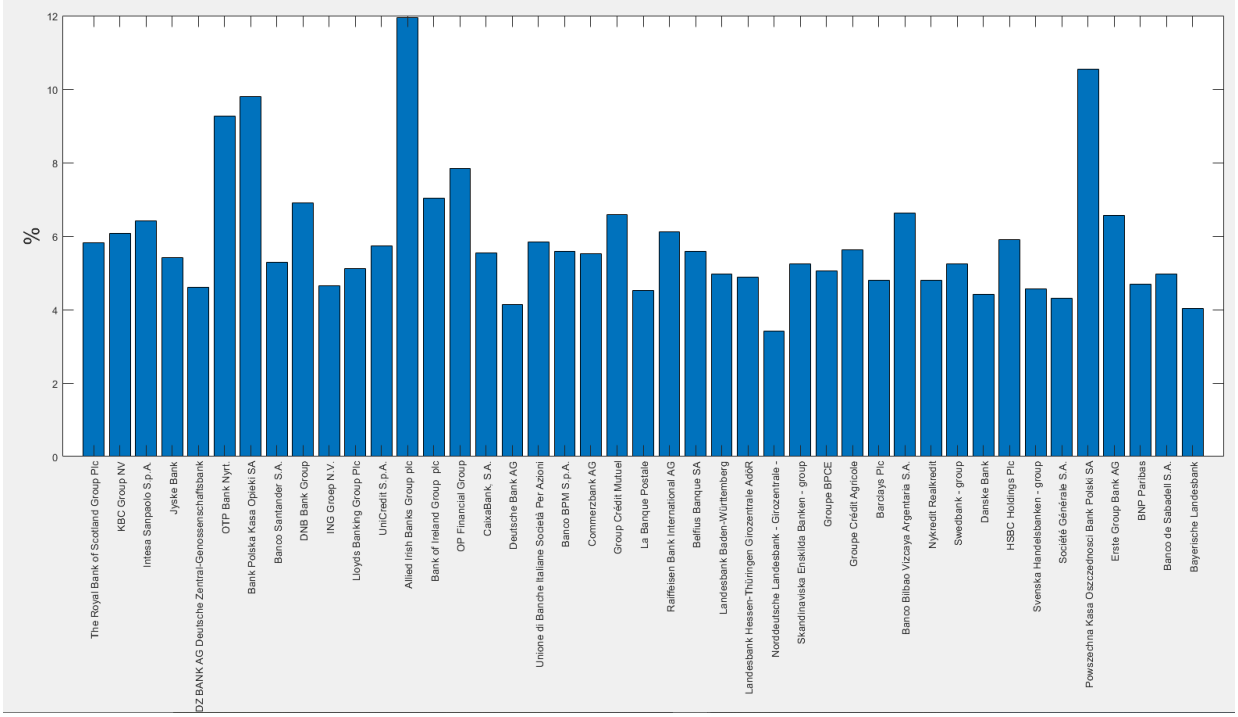

Figure 5: Capital ratios by bank.

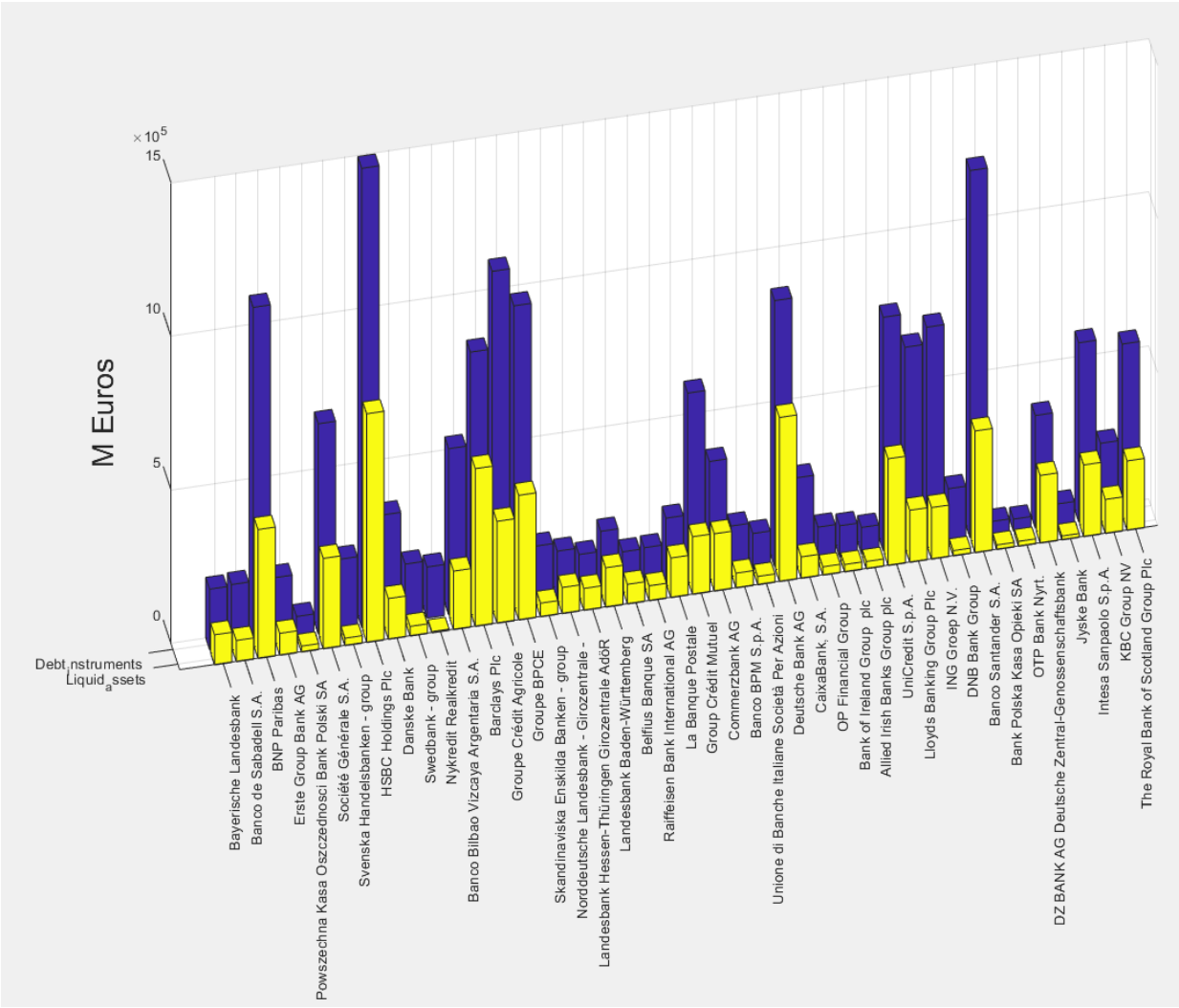

Figure 6: Liquid and debt instrument by bank.

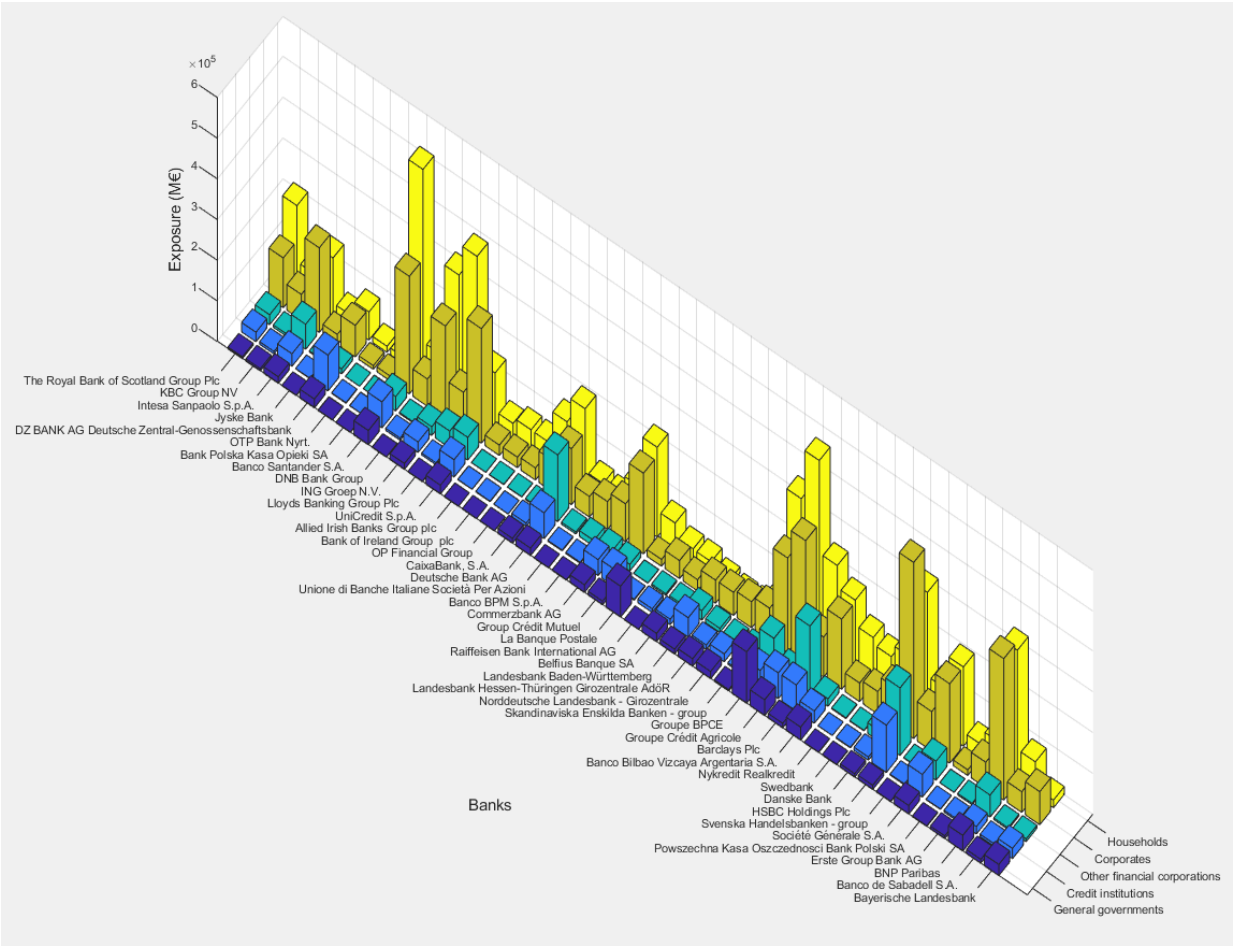

Figure 7: Loans and advances by counter-party.

Direct.png

Table 2: Stress tests results.).

Contagion.png

Table 3: Stress tests results, capital evolution after a initial losses on all sectors (15% loss on original exposures.

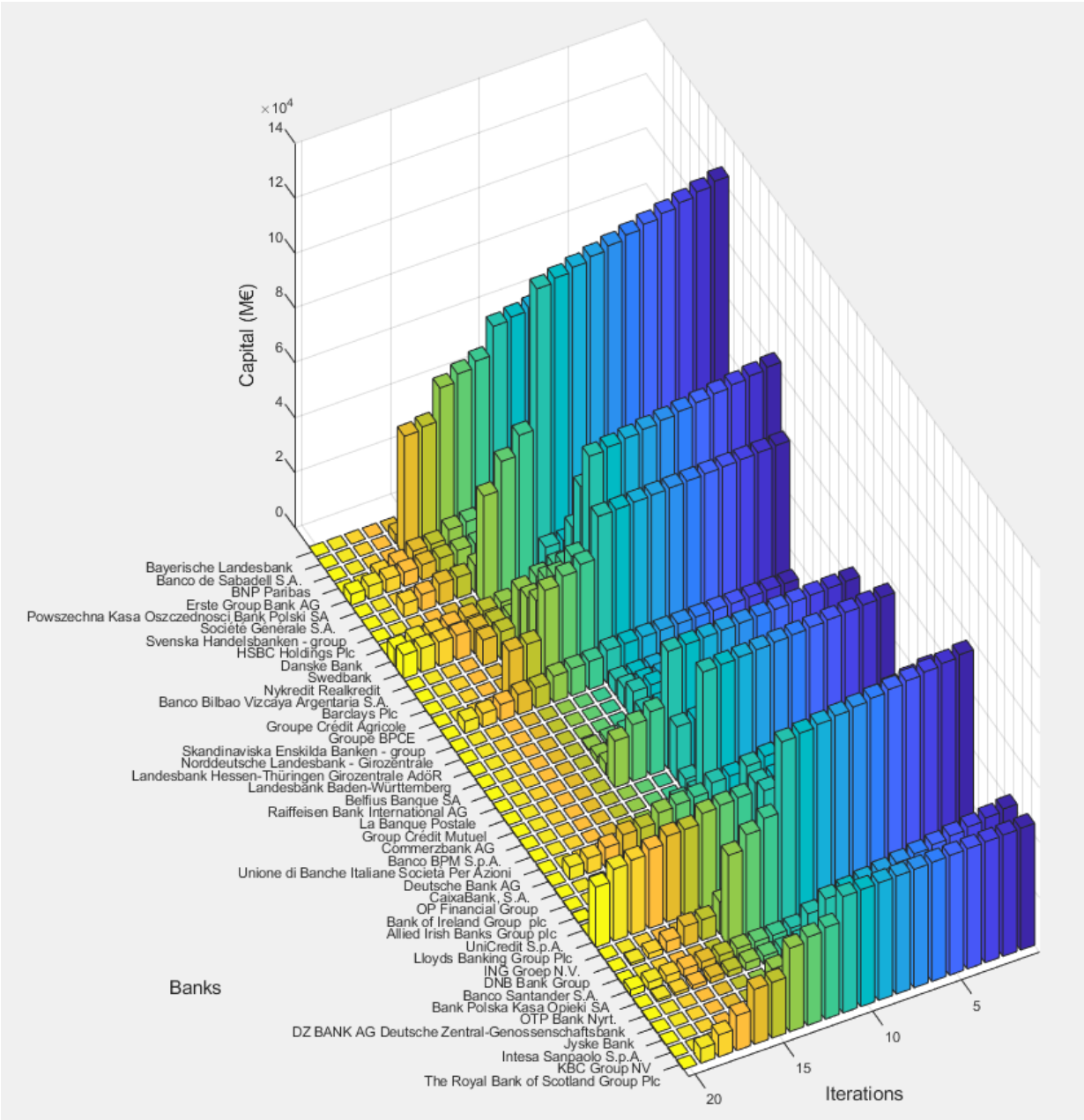

Figure 8: Stress tests results, capital evolution after construction is hit (25% loss on original exposures).