The role of digital technology in Macro-financial linkages

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Abstract

The aim of this paper is to investigate the impact of digital technology on the relations between the financial sector and the real economy in EU. The IT revolution brought new factors that influenced the traditional banking market. Banks were forced to compete not only with other players from the banking sector but also with unregulated FinTech companies. Based on into two models using simple panel data regression and the interacted panel vector autoregression model this paper confirms the impact of FinTech on credit grow. Finally, based on the quantitative analysis this paper confirms that modern technology has had an impact on bank lending, especially on loans for households.

Keywords: real economy, macro-financial linkages**,** traditional banks, loans, digital technology.

JEL Codes: G21, F36; G2; G21; G34.

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Introduction

An advanced and efficient financial system is a crucial factor determining the pace of economic growth in every county (Borio, al. 2001, Borio, 2014). The main element connecting the real economy with the financial sector is bank credit. On the other hand, the demand for credit depends on the macroeconomic situation. In the case of business entities, it depends on the availability of alternative financing sources or their financial standing. A crucial factor affecting bank credit dynamics is the structure of the banking sector which fluctuates depending on market circumstances and it affects both the demand and supply side. Competition on the credit market is related to market players' strategies and it affects the profit of banks, the development of bank credit, and consequently, economic growth. Thus, its level also affects the relations between the financial sector and the real economy.

Since the global financial crisis of 2008, we have observed new trend in financial sector focused on business model related with digitalization and FinTech (BCBS, 2018; Thakor, 2020). Along with the progress of innovative technology, they have become the key transformation factors of the financial sector on a global scale. The players include both small firms (startups) and big technological firms BigTech (BIS, 2020, the importance of which is growing in the transformation of the market of services that used to be restricted only for banks. The digital transformation of the financial sector is challenging banks' business models. According to Vives (2017), competitors from the FinTech sector are putting pressure on the traditional business model of banks. However, compared to FinTech companies, banks have two competitive advantages in the financial market, they can borrow cheaply, have access to cheap deposits and have access to explicit or implicit insurance by the government, and they enjoy privileged access to a stable customer base. It seems, however, that the differentiator for banks, which provides them with loyal customers, is the element of trust and the fact that traditional banks, unlike the new players, are institutions of public trust (Thakor, 2020). Endogenously, banks have stronger foundations to maintain trust. And trust is asymmetrical - it is harder to gain it than lose it. Currently, the significant macroeconomic uncertainty has been reflected in financial market tensions in EU, with credit risk, liquidity risk and funding.

This study endeavours to describe the current knowledge on the relationship between the financial sector and the real economy in the context of new competitors active on the credit market (affiliated with innovative technology). Also the pandemic has had a tremendous impact on the growth of the FinTech companies. This companies may also be

perceived from the perspective of the financial and non-financial sector intermingling, which introduces a new quality to the study of relations between the financial sector and the real economy.

The aim of this paper is to investigate the impact of digital financial technology and FinTech on bank credit in EU in the context on macro-financial linkages. This paper consists of qualitative and quantitative analysis. In the theoretical part, the article broadly describes the role of credit in the economy, its role and various channels of influence. Also, in the theoretical part In the theoretical part this paper confirms the big role of FinTech companies in shaping the new conditions of competition on the financial market. Finally, the quantitative investigation based on panel data confirms that new technology had an impact on the credit market in EU.

1 Credit market imperfections

The literature provides a distinction among the following channels/mechanisms affecting the relation between the financial sector and the real economy on the supply side and demand side. The above channels focus on the banks' special role in the financial intermediation process. A study on the credit channel enjoys a prominent position in the literature on monetary policy transmission. The first trend concentrates on credit rationing. Changes affecting banks' balance sheets, chiefly their liquidity, are the most likely to affect the overall supply of financing. The above channels overlap, and their functioning in the relations between the financial sector and the real economy is affected by the banking sector’s market structure.

Financial market imperfections looking at the supply side i.e.: the credit channel, capital channel, as well as leverage channel, which consider information asymmetry influence corporate loans and household loans. The above channels focus on the banks' special role in the financial intermediation process. A study on the credit channel enjoys a prominent position in the literature on monetary policy transmission.

The reliance of businesses on bank financing affects how the monetary policy is transferred to the real economy by the credit channel. Monetary policy measures may affect banks’ lending capacity as the measures influence the supply of funds to which a bank has access by affecting the accessibility of deposit funds and, more generally, the banks’ financing costs and, as a result, the volume of lending a bank can provide. Bernanke and Blinder (1992), were the first to discuss the effect of monetary policy on the supply of bank

lending. They showed that restrictive monetary policy in the US was conducive to restricting the overall credit volume. To identify the changes in credit demand, attempts were made to determine and analyse such bank characteristics that do not affect credit demand but have an influence on its supply.

In case of corporate loans, financial market imperfections normally affect small enterprises, particularly during financial distress. The reason behind this is that such entities have more restricted access to financial markets due to insufficient collateral or being less transparent for external investors, and their projects are indeed more vulnerable from a cash-flow perspective (cf. Petersen and Rajan 1995; Fazzari et al. 1988). In empirical studies on corporate lending from a demand perspective the amount of trade credit is often taken as a measure of credit rationing. In case of households, due to imperfections, including the incapacity of borrowing based on their lifetime income, households may be subject to restrictions with respect to borrowing, thus they may resort to more precautionary saving. In this way, household consumption may be highly vulnerable to transient fluctuations of income. Normally household loans prevail in banks' portfolios. Therefore, the central bank's monetary policy and macroprudential policies which emerged in response to a crisis (Calomiris 2009) chiefly target the mitigation of households' credit risk. Studies on household loans can be broken down into consumption and mortgage credit. A number of empirical works regarding household loans have corroborated the thesis that changes in aggregate consumption positively correlate with delayed or anticipatable changes in income growth or/and bank credit growth (cf. Flavin, 1981; Deaton, 1992; Jappelli and Pistaferri, 2010). Moreover, it has been demonstrated that financial imperfections related to housing markets have consequences reaching beyond their influence on an individual household (Almeida et al. 2006).

The financial crisis of 2008 confirmed that deepening knowledge on the relations between the financial sector and real economy was critical. It brought to the surface the significance of the impact of sudden fluctuations in the prices of assets, credit dynamics and capital flows on the financial condition of households, businesses, and consequently, on the debt of sovereign countries, which caused a deep recession. The relations issued enormous challenges for the fiscal, monetary and sector policies. In order to mitigate the problem of lending pro-cyclicity, a framework for macroprudential policy was devised. Theoretically speaking, pro-cyclicity would not have emerged if the banks had maintained adequate capital buffers throughout the cycle, thus improving their capital position during recovery, to withhold losses in the times of a downturn. The notion of pro-cyclicity may be linked to the

causes of crises, the characteristics of supervisory boards and reforms aiming to improve financial stability (cf. Acharya and Richardson, 2009).

The reliance of businesses on bank financing affects how the monetary policy is transferred to the real economy by the credit channel. Bernanke and Blinder (1992). were the first to discuss the effect of monetary policy on the supply of bank lending.

2. Credit market competition

A crucial factor shaping the credit market is the market structure, which affects the level of competition and banks' market strength. Notwithstanding, theory alone does not provide clear-cut conclusions concerning market structure and competition among banks on credit supply and demand (cf. Degryse et al., 2009). On the one hand, following the traditional stance in the theory of economics, market force results in a lower supply, albeit at higher costs. On the other, considering information asymmetry and agency costs, it is conducive to a phenomenon that shows a positive or non-linear connection between market force and credit access.

The theory suggests that any departure from perfect competition results in restricting the borrowers' access to credit, at higher prices. The impact of market structure on banks' lending and deposit operations was first studied by Pagano 1993. Guzman 2000 showed that a monopolistic structure will more likely produce credit rationing than a competitive banking market. However, it should be noted that there is a long-standing scientific debate regarding a solution the problem, and there is no scientific consensus whether banking sector competition will generate higher or lower stability (Vives 2016; Bikker and Spierdijk, 2017). Cetorelli et al. 2001 confirmed that, in general, competition growth in the banking sector favours economic development, yet there are channels via which it may have an adverse effect, e.g. higher competition may lead to a higher lending volume and a higher share of non-performing loans. Ratnovski 2013 emphasised that it is necessary to develop a new competition policy for banks concerning products, not only market structure. Of importance is the relation between bank system consolidation and concentration changes evoked by the relation versus banking sector competition. The majority of studies on the relations between concentration growth and competition conclude on the basis of empirical analyses that there are no clear links between a system's concentration growth and its competition level (Claessens and Laeven 2004). The findings of empirical studies on the direction of changes in the level of competition among banks in the EU generally showed competition growth before the crisis, and a decline during the crisis in the banking sectors of Central and Eastern Europe (inter alia Pawłowska 2014;

Clerides 2013). However, the outcome concerning banking sectors in Western Europe is ambiguous (cf. Bikker 2012; Weill 2013). Contemporary literature also focuses on the effect of competition in the banking sector on how monetary policy transmission works (Beck et al. 2004, 2013; Leroy and Lucotte 2017; Fungáčová et al. 2017).

In recent years, a growing volume of analyses have been pointing to the important role of the shareholding structure in shaping the growth of banks' credit portfolio (Bonin et al. 2005; Martinez Peria, Mody 2004; Meriläinen 2016; Bhaumik and Piesse 2008; De Haas and Van Horen 2011, 2012). The authors who described the effect of the type of shareholding with respect to the credit market in Central Europe included Cull and Martínez Pería 2013; Kouretas et al. 2016; Allen et al. 2017. In particular, Cull and Martínez Pería 2013 showed that foreign banks are characterised by a more rapid credit expansion versus the domestic banks on Eastern Europe. Based on panel data concerning the dynamics of bank lending in the EU in the period 2010-2016, Kouretas and Pawłowska 2020 found differences among the determinants of several types of bank loans (consumer, mortgage, and corporate loans) in Central and Eastern Europe (host countries for foreign capital) and Western Europe. Finally, based on panel data on the dynamics of bank lending in the EU in the period 2010-2016 and on the basis of GMM estimation, Kouretas and Pawłowska 2020 found differences among the determinants of various types of bank loans (consumer, mortgage and corporate loans) in Central and Eastern Europe (host countries for foreign capital) and Western Europe.

2.1 The effect of digital technology on credit market

The technological revolution 4.0 began in the 60s of the twentieth century with the discovery of the microprocessor at Intel, then there was the development of computers called "main frame" and in the 80s PCs and local networks appeared. A milestone for the industrial revolution and the emergence of the global network was the creation of the Internet in 1990, which contributed to the creation of electronic banking. Another impetus for the development of new technologies was the invention of the mobile phone. With the advent of the so-called Industrial Revolution 4.0 (cf. Schlechtendahl, Keinert, Kretschmer, Lechler & Verl, 2015; Nayernia, Bahemia, Papagiannidis, 2022), the financial sector has also changed. One of the ideas behind the Industrial Revolution 4.0 was that all participants connect and exchange information with each other. The basis of the Industrial Revolution 4.0 was the invention of the Internet. On the other hand, the invention of the telegraph in various forms is considered to be the precursor of the Internet (see Figure 1 in the Appendix).

With the development of PCs (from 1980), stock exchanges developed, and physical trading floors were replaced by electronic trading and settlement systems. Technological progress has caused the appearance of new competitors for traditional banks on the credit market. They can markedly change the world of financial providers. FinTechs as well as Big Tech[3], i.e. big, well-established firms whose operations affect both the financial products and the infrastructure of financial institutions, are among the new entrants to the financial sector. The new competitors offer a wide array of products and provide easy access to the financial market at lower costs. The competitors also include neobanks, which hold a banking licence but do not have traditional branches.

Just like the global internet network in the early 1990s spurred on the development of electronic banking, the present financial technologies abbreviated as FinTech or Big Tech have brought on revolutionary changes in financial services. What contributed to the transformation was the employment of mobile telephony in mobile payments (Nicoletti 2017; Blakstad and Allen 2018; Scardovi 2017, Boissay, Torsten, Gambacorta, Hyun Song Shin, (2021). Initially, internet banking split the banking world. The first group incorporated banks operating through traditional branches, developing www-based solutions and offering their services online. For those institutions, web services were but additional distribution channels for banking products and services. The other group comprised virtual banks, i.e. having no traditional branches, offering remote account access, with no option to visit a traditional bank branch. Similarly, there are banks which use FinTech technology as an additional distribution channel, as well as new banks (neobanks) which do not have traditional branches[4]. For non-banking FinTech companies (e.g., start-ups), innovations based on digital technologies are the core business. They are particularly active in such areas as new payment systems and automated investment advisory. Also, ATMs are among the product innovations that fostered the development of the FinTech sector (Nicoletti, 2017).

It should be noted that financial market imperfections are also of significance to the new players. Historically speaking, the operations of traditional banks aiming to foster relations with their customers used to be considered a factor lessening information asymmetry between the funds provider and the credit market customer (inter alia Akerlof 1970; Stiglitz and Weiss 1981), both ex ante risk (negative selection), as well as moral hazard may be mitigated by

[3]Big technological firms which expand their operations to include direct financial services or those closely approximating financial products, e.g. Amazon, Facebook, Google, Apple, Alibaba and Tencent. The business model of the big technological firms involves providing a large number of data users with direct interaction (BIS 2019, p.55).

[4] https://www.bankingsupervision.europa.eu/about/ssmexplained/html/FinTech.pl.html.

banks on account of their experience in finding and monitoring borrowers (Leland and Pyle 1977; Diamond 1984). However, the spread of internet use and its platforms has enabled the immediate of matching lenders and borrowers thanks to so-called peer-to-peer loans (P2P) (Morse, 2015). For this reason, the new competitors in their operations are already and will continue to exert a tremendous level of impact on the existing bank-borrower relations, as one of the banks' fundamental functions is their ability to mitigate information problems in relations between borrowers and lenders.

In the era of digitalisation and internet use growing ever more common, it is important to analyse the effect of FinTech financial innovation on the market structure, including on the emergence of channels through which innovative technologies affect the competition level in respective market segments. As already mentioned, studies measuring competition in the banking sector draw theoretical and empirical models from the industrial organisation theory. The models identify the main factors determining marketing decisions made by banks (Pawłowska, 2014). Following the 2008 financial crisis, which validated the banks' rising role in the economy, particular attention was drawn to the growing concentration of the banking sector and a rising size of TBTF banks. A classic model based on the SCP paradigm suggested that a more concentrated system is marked by lower competition, which enhances the likelihood of collusion, which in turn drives bank profits and a positive relationship between concentration and bank performance (Bain, 1951). Performance is measured through profitability, effectiveness, and productivity (Martin, 1989). Bank's competitors are non-banking financial institutions, including FinTech companies providing financial services. There are two types of players referred to as FinTech: banks using FinTech digital techniques and non-banking FinTech firms (including start-ups) offering products like banks operating on the payday loan market.

The concepts related to the functioning of the FinTech sector are FinTech loans and Fintech credit (Cornelli, Fiore, Gambacorta Manea, 2023), Acharya, Cetorelli and Tuckman, 2024). On the one hand, there was a significant change in the payments segment as a result of the use of new technologies, while on the other hand, the activities of FinTech companies gradually covered basic banking services, including loans. Like banks, they provide consumer loans, corporate loans, and mortgage loans. Loans granted through them are growing rapidly, although they are still small compared to loans granted by traditional intermediaries (Claessens et al., 2018). There is no internationally valid definition of a FinTech loan. It is broadly defined to cover all loans that are supported by electronic (online) platforms and not operated by traditional commercial banks. The provision of loans by the FinTech sector

enables wider access to financing. This approach is in line with the position of the FSB (CGFS-FSB, 2017). The above definition of a FinTech loan covers all lending activities supported by online electronic platforms (depending on the jurisdiction, these platforms are referred to as "peer-to-peer (P2P) lenders", "loan-based crowdfunds" or "market lenders"). Due to such a wide definition of FinTech loans, compiling aggregate data is challenging, all the more as the time series covering this phenomenon are quite short. Initial estimates were published in Claessens et al. (2018, pp. 29-49). However, the increasing use of the Internet and platforms based on it has made it possible to match lenders and borrowers directly through peer-to-peer (P2P) lending. In this loan model, the intermediation of financial institutions is not required, and the contact between lenders and borrowers is provided by a credit platform. Also, the FinTech revolution brought new factors that influenced the financial sector and had an impact on sustainable finance (Bandi and Pandimiglio, 2022). However, pro-cyclicality may arise from a greater concentration in certain market segments, as well as from financial flows becoming large and unstable on FinTech lending platforms (which may not currently be accessible to macroprudential tools).

One of the important problems a borrower faces is how to check creditworthiness, i.e. how to monitor borrowers. Another critical issue is that the borrowers must bear the responsibility for appropriate use of the funds borrowed. Bank's traditional functions include borrower information processing. While FinTech institutions have a comparative advantage with respect to Big Data and analytics, the banks' long-term relations established with their customers helped them not only to build reputation and confidence, but also to monitor borrowers and lessen the moral hazard. A question arises as to what extent the massive-scale use of data and advanced technologies will replace the existing customer information and what advantage traditional banks have thanks to their customer relations. It is of particular importance during the pandemic-borne crisis, where traditional banks should play a significant role in financial intermediation. In today's world, however, customers communicate better and are better informed. They are also more sceptical and demanding. What is more, they demand better and more personalised services. Therefore, adaptation and special attention being drawn to products' usefulness, convenience of use and accessibility have become a basic requirement for banks. This can help build and maintain customer loyalty, although, first and foremost, it is a way to stand out on the market.

3. The role of digital technology in the context of the relations between the financial sector and the real economy: empirical results

3.1 Models description

In recent years, the FinTech sector has been growing faster than traditional finance and will therefore have an enormous impact on the lending market. The development of the internet, digital technologies and mobile devices has brought about innovative changes in the financial sector. Currently, traditional banks must adapt their business models, which has significant consequences for the future of the entire financial sector (Petralia et al. 2019). The so-called traditional banking or traditional banks include banks that have a universal banking business model, but also banks that conduct investment activities; for the sake of simplicity, the word traditional will be used to describe the combined model of universal banks (Blakstad, Allen, 2018, pp. 148-149). Traditional banks align their business models with digital techniques, which entails profound consequences for the future of the entire financial sector (cf. Petralia et al. 2019). The banks traditionally focus on products, while the new players shift their attention towards customers. Buchak et al. 2017 found that on the US mortgage market traditional banks provide products of higher quality than those of FinTech (they stressed, however, that the traditional banks lose their market share because of a greater regulatory burden). The fact shows that whether new FinTech firms shall enter the financial intermediation market will be to a large extent up to the regulations and government guarantees for traditional banks (Vives 2019). Also, FinTech may boost the development of green finance, which addresses environmental protection or climate change. Green bonds are the examples of green financial instruments. Globally the green bond market grew by an average of 50% per year in the period 2015-2020 (see: Pawłowska, et al., 2022).

However, despite the increasing number of studies on the development of the FinTech sector and sustainable growth, there is still no specific quantitative research on how the above changes affect the development of the bank loan market. While the consolidation of the banking sector leads to a reduction in competition due to the emergence of ever-larger banks, the FinTech sector, in turn, stimulates the level of competition not only in the banking sector, but also in the entire financial system (cf. Navaretti, Calzolari, Pazzolo, 2017).

In the empirical part was examined the impact of new technologies on the bank lending in EU with using simple regression model based on panel data. The panel data set was constructed based on the annual panel data at the level of EU countries. The set of used data contained microeconomic and macroeconomic data in the form of a (cross-sectional and time-series) panel for 28 countries of the European Union excluding Croatia and Romania but

including data for UK. The excessive credit growth, in particular for households, may be responsible for deepening the imbalances in the economy (Goodhart and Hofmann, 2008; Reinhart and Rogoff, 2011; Laeven et al., 2016). The financial crisis and the increase in the systemic risk associated with cross-border bank activities led to a reform of the financial supervision process, including the introduction of macroprudential policy and its tools.

Accession to the EU in 2004 for new EU countries created additional challenges for domestic financial institutions by improving their competitiveness through mergers and acquisitions along with the further development of products for households and small- and medium-sized businesses. The new EU countries have been playing the role of host countries for many foreign banks located in Austria, Belgium, Greece, Germany, France, Italy, the Netherlands, Portugal, and Spain. Therefore, the banking sectors in the CEE countries are characterized by a high level of concentration and the presence of foreign ownership (Anginer et al., 2016) compared to the highly developed banking sectors in Western Europe (see Figure 2). Furthermore, the banking sectors in Central and Eastern Europe are small compared to the old Union, and banks use relatively simple, traditional business models and focus on deposit and lending activities for business and households.

The empirical study consists of two parts. The first examined the impact of innovative technologies on the bank credit market with using simple regression model. The second examines the impact of innovative technologies on the profitability of banks and the bank credit market with using pVAR model. When examining the influence of the FinTech sector on bank lending, it should be distinguished whether we are examining the FinTech sector as an element within the banking sector (innovative technologies used by traditional banks) or as an external element outside the banking sector. Similarly, the FinTech technology can be used by banks as an additional distribution channel or new banks (Noeobank) without traditional branches may be formed. Furthermore, it should be determined whether we are to refer only to the retail customer and the lending market, or to the entire market of credits and loans for the non-financial sector. Traditional banks are adopting new digital technologies. Product innovations in traditional banks include ATMs and modern PayTech payment systems using applications for mobile devices (smartphones).

The aim of the research was to verify the hypothesis concerning the impact of FinTech sector on bank credit market. In this study, we analyse bank credit in the context of market concentration and business cycle in case to test relation between financial sector and real economy. We measure concentration in the banking sector as the share of the 5 largest banks in total assets (CR5) and the Herfindahl-Hirschman index for assets (HHI). To conduct

quantitative research on the factors influencing the dynamics of several types of loans and profitability of banks relation in the context between financial sector and real economy, an appropriate econometric model was constructed. The relation between the situation on the financial market and the macroeconomic condition of the economy is dynamic and bilateral. For this reason, we use two empirical methodologies: simple panel data regression and pVAR model. An alternative econometric approach to dynamic panel models is the construction of a vector regression panel model (VAR/pVAR panel), whose structural parameters are also often estimated using the GMM estimator (cf. i.a. Góes, 2015; Ganelli and Tawk, 2016; Canova and Ciccarelli, 2013; Leroy and Lucotte, 2019; Kouretas and Pawłowska, 2020). Finally, in case to evaluate relationship between real economy and financial sector we used the linear panel VAR model (panel VAR). Finally, we contracted two models based on with on country level data.

The macroeconomic data from individual EU countries were obtained from publicly available online databases of international organizations, such as the International Monetary Fund, the European Central Bank (Statistical Data Warehouse) and Eurostat. The following variables are considered to be variables describing new technology: share of the number of individuals using the internet for online banking in the population, with internet banking understood as electronic transactions, such as bank transfers or direct debits, as well as checking the account balance or history; ATMs allowing authorized users to withdraw cash, with authorization usually made via a payment card and three types of variables used (total number of ATMs, number of ATMs per 1,000 km2, and number of ATMs per 100,000 adults); share of individuals using the internet in the population; number of mobile phone subscriptions per 100 people; internet access from a mobile device, laptop, or notebook (percent of people); and number of secure web servers per 1 million people.

The research period covered the years 2004–2021. Some variables have been available since 2013. Due to missing data, this was an unbalanced panel. The second data set contained microeconomic and macroeconomic data in the form of a (cross-sectional and time-series) panel for EU countries. The panel data set was constructed based on the annual panel data at the level of EU countries. The set of used data contained microeconomic and macroeconomic data in the form of a (cross-sectional and time-series) panel for 28 countries of the European Union instead of Croatia and Romania but include data for UK. Macroeconomic data for individual EU countries was obtained from publicly available online databases of international organizations, such as the World Bank, International Monetary Fund, European Central Bank (Statistical Data Warehouse), Eurostat, Federal Reserve Bank of New York.

Data on innovative technologies (including payment and card services) come from the International Monetary Fund, the European Central Bank (Statistical Data Warehouse) and Eurostat (data on internet use and mobile telephony).

Additionally, we consider new FinTech variables from the study: Cornelli, Doerr, Franco, & Frost, (2021). It should be noted that FinTech solutions have emerged in the last 5–6 years, so analysing them in earlier periods is difficult. Another limitation, in addition to missing data, was the need to standardize the data for the study. Especially useful information for the panel model was the value of FinTech credit in the European markets. However, due to significant data gaps and a short time series, the variable could not be used in the estimations of the panel data and was ultimately not used in the empirical model. Certainly, the values for this variable will be supplemented over time. The value of FinTech credit will become a key variable for analysing the financial innovation sector. Finally, panel data covered the years from 2010 to 2021 and included data from 28 EU economies. Some variables have been available since 2013. Due to missing data, this was an unbalanced panel. Descriptive statistics of the collected data are presented in Table 1 of the Appendix.

FinTech develops independently from the banking sector; however, the banking sector is a major implementation field for FinTech solutions. Therefore, in the model, we considered the variables determining new technologies inside the banking sector, outside the banking sector and the variables relating to the FinTech sector (see Pawłowska, 2022). Secondly, the analysed phenomenon was empirically measured based on a quantitative study using econometric techniques on a constructed panel of data. The panel data included annual data at the national level of 28 EU economies. Data in the panel covered the macroeconomic situation (e.g., GDP growth) in individual EU economies, the level of concentration in individual banking sectors, the situation in the banking sector and bank performance, e-banking and the FinTech sector.

To verify the research hypothesis, the econometric two models were estimated using panel data analysis techniques. The first model based on equation (1) concerns the impact of the digital techniques on bank lending of the EU banks and take into account the impact of the COVID pandemic. The second model based on equation (2) with using pVAR methodology concerns the relation between finance and real economy.

3.2.Results of Panel Data Regressions: model 1

In this chapter we present the contraction and results of model based on panel data regression.[5] In the first model, the dependent variable is banks' loans, while the independent variables are: concentration of the banking market, vectors of banking performance variables, GDP, digitalization and FinTech. Data concerning loans are from European Credit Research Institute (ECRI)at the Centre for European Policy Studies (CEPS) for banking sectors form Statistical Package 2022 "Lending to Households and Non-Financial Corporations in Europe". The model uses two types of variables to describe the innovative technology (inside and outside the banking sector) and variables describe the FinTech sector.

Equation (1) represents the output specification of the constructed econometric model:

$$\Delta Y_{c,t} = \mu_t + \gamma_c + \alpha_1 MS_{c,t} + \beta_k \sum_{k=1}^{n} X_{c,t} + \beta_0 COV_{c,t} + \alpha_2 GDP_{c,t} + \alpha_3 DigTech_{c,t} + \\ + \alpha_4 FinTech_{c,t} + \varepsilon_{c,t} \quad (1)$$

where the explained variable $Y_{c,t}$ is four types of loans variables: loans for households (L_H), loans for nonfinancial corporation (L_NFC), total loans (T_L), total loans to GDP (L_GDP) and total loans per capita (L_PCs) and in country *c* in year *t*[6].

As explanatory variables the following variables were used in country *c* in year *t*: $GDP_{c,t}$ is the business cycle variable, $X_{c,t}$ is a vector of control variables that reflect bank performance in banking sectors*;* $MS_{c,t}$ is concentration in banking sectors, $DigTech_{c,t}$ is a vector of variables that capture digital technology (inside and outside the banking sector).

- as variable describing $GDP_{c,t}$ was adopted us GDP growth and GDP *per capita* in country *c* in year *t;*
- the vector of control variable $X_{c,t}$, describes the profitability in the banking sector as the expresses in the model as return on assets (*ROA*) and return on equity (*ROE*) in country *c* in year *t;*
- the concentration ratios $MS_{c,t}$ as indicators of market structure: the share of the five largest credit institutions in total assets ($CR5_{c,t}$) and as the HHI for assets (the sum of the squares of the market share of individual banks)[7], for country *c* in year *t;*
- the variables derived from payment statistics from the ECB were adopted as variables describing the new technology *inside* the banking sector in country *c* in year *t*: *INTER*, *ATM*;

[5] The model was estimated with tree techniques: based on cross-sectional data using the MFE estimator, pool regression, and on cross-sectional data using simple FE estimator.
[6] Such a study was carried out additionally evaluation with ROE, but the results are not presented.
[7] The HHI index was used for the robustness check in the regressions based on equation (1).

- as variables describing the new technology *outside* the banking sector, we considered: *Mobile* and server for country *c* in year *t;*

Also, we take into account the impact of the COVID pandemic on the credit market and the performance of banks. In case to evaluate the impact of a pandemic on the banking sector was defined a binary variable defining the COVID-19 pandemic (COV): COV = 1 for 2020 - 2021 years, COV = 0 otherwise.

Furthermore, we consider the following new FinTech variables from the study: Cornelli, Doerr, Franco, Frost, (2021):

- *FinTech* is define us a number of transactions in the FinTech sector in relation to GDP for country c in year t.

Tables 2-6 in the Statistical Appendix present the results of the panel regressions based on equation (1). The coefficients of the model (1) were estimated by linear regression on panel data using the STATA package[8]. In Table 2, the negative and significant coefficient α_1 was found for CR5 (Column 1). This means that concertation in the banking sector had a negative and significant impact on credit grow in the EU. In Table 2, the positive and significant coefficient α3 was found for ATMs located in the reported country (Column 3), percentage of people using online banking (Columns 1–3). This means that digitalisation in the banking sector had a positive and significant impact on the profitability of banks in the EU. Variables defining mobile technologies (*MOBILE*) also affected the level of profitability in the banking sector. In Table 2, a negative and significant coefficient α_4 was found for the variables indicating the share of people using mobile devices to access the Internet (*MOBILE*) and for the variable indicating the share of people ordering products and services online (Columns 2). However, the coefficient of the variable *INTER* turned out to be positive, which means that Internet use for Internet banking affected banks' profitability. This implies that new FinTech had a negative and significant impact on profitability in the EU. On the one hand, new technologies inside the banking sector had a positive impact on bank performance. On the other hand, new technologies outside the banking sector had a negative impact on bank credit[9]. The results of the quantitative study presented in Tables 2-5 showed that the COVID-19 pandemic negatively affected the performance of traditional banks. In addition, the use of technological solutions in banks also positively affected their profitability as indicated by the positive and significant coefficient on the variable *INTER* (Column 1). On the development of the FinTech sector, COVID-19 pandemic, affected positively as indicated

[8] MFE is multiple levels of fixed effects estimator (including heterogeneous slopes).
[9] Fixed-effects estimator (FE).

by the estimation results. However, the COVID-19 pandemic can be said to have caused accelerated development of digital technologies and the FinTech sector.

To sum up, the results of the models allowed us to verify the hypothesis that innovative technologies have an impact on bank loans. Also, the findings confirm the impact of the COVID pandemic on the FinTech and traditional banking sector. However, the results showed that the pandemic had a positive impact on the development of the FinTech sector. On the one hand, the pandemic contributed to an economic downturn and decline in banks' results, but on the other hand, it caused the development of sales channels using new FinTech technologies.

Due to the pandemic, economic lockdowns are bound to result in higher special-purpose reserves due to a decline in bank asset quality. At the same time, the decline in customer business activity reduces banks' margin of revenue. In such a tough situation, FinTech solutions are proving to be a source of cost reductions for banking operations through the efficiency gains offered. Improving data statistics in this area remains a critical issue that will improve monitoring of this phenomenon and analysis of the competitive advantage of FinTech providers compared to traditional banking services.

3.3.Results of pVAR model: model 2

The second model is based on the linear panel VAR. Model (panel VAR) can describe the interactions between macroeconomic variables and financial activity indicators and is a standard tool in the literature on macrofinancial linkages. Therefore, to strengthen the results obtained with the use of the GMM model, the results of additional estimates using the pVAR model (Leroy and Lucotte, 2019) are presented in this section. The pVAR model is a combination of the single dynamic equation of the panel model and the VAR model. The VAR models (formulated by Sims (1980)) are multiequation models in which each variable is explained by its own lags and the lags of the other explained variables. To illustrate the differences in credit determinants among individual EU countries, we compare the response function (impulse response function [IRF][10]), which we estimate under the pVAR model. In the panel vector regression model (VAR panel),[11] the analysis concerns bidirectional, symmetrical, and linear relations between macroeconomic variables.

[10] The IRFs illustrate how shocks (sudden changes, η_t, current in period *t*, as well as lagged) affect the changes in value *y*, that is, the IRF plot shows the responses of the variables *y* to various impulses in the model disturbance.

[11] Usually, for the purposes of identifying the VAR model, Cholesky decomposition is used.

The general VAR model has the following form[12]:

$$y_t = A_0 D_t + \sum_{l=1}^{k} A_l y_{t-l} + A_1 X_t + \gamma_{,t}, \quad (2)$$

where y_{it} is the vector of observations on the current values of all k variables in the model; y_{t-l} denotes the matrix of lagged observations, with lag $l > 0$; A_l signifies the matrix of parameters with time constants but bank-specific lagged variables; D_t represents the matrix of deterministic equation components (e.g., zero-one variables); $\gamma_{,t}$ represents the matrix of stationary random variables having an independent normal distribution with zero mean and variance; and A_1 denotes the parameter matrix for variables X_t.

We build our panel VAR for macro financial policy analysis. The panel VAR model in a recursive (structural) form with an one lag of order one was as follows:

$$Y \begin{pmatrix} MA_{ct} \\ FI_{ct} \end{pmatrix} = X \begin{pmatrix} MA_{ct-1} \\ FI_{it-1} \end{pmatrix} + T_c + \gamma_{c,t}, \quad \ldots\ldots\ldots\ldots \quad \ldots\ldots(3)$$

describing the interactions between the two macroeconomic variables (GDP and GDP per capita), $\mathrm{MA_{ct}} = \left(\mathrm{MA_{ct,1}}, \mathrm{MA_{ct,2}}\right)'$, and the two financial activity indicators (loans and FinTech), $\mathrm{FI_{ct}} = \left(\mathrm{FI_{ct,1}}, \mathrm{FI_{ct,2}}\right)'$, is a standard tool in the literature on macrofinancial linkages. In the model γ_{it} is a multivariate and independently distributed error term, matrix Y includes the parameters determining the contemporaneous (instantaneous) relationships between dependent variables, matrix X includes the parameters at the first lag of dependent variables, and $\mathrm{T_i}$ is a time-invariant parameter describing a country's FE.

To ensure the economic identification of structural shocks, γ_{it}, Y was restricted to be a lower triangular matrix with variables on the main diagonal. According to these restrictions, endogenous variables are ordered in such a way that the first one does not depend immediately on the other endogenous variables, and the following ones depend on all previous endogenous variables except for the next ones.

This model attempted to assess the impact of FinTech solutions on the development of bank lending for diverse types of loans: loans for nonfinancial corporation, lending for households loans and total loans. Also, the equation 3 was accounted for the concentration indicators, GDP growth (GDP), and variables that consider the new digital technology within the context of pVAR analysis). Spurious or nonsense regression is always an aftermath effect of time series data with a unit root problem. To check stationarity, Fisher-type unit-root tests were used. To analyse the impact of FinTech financial innovation on bank performance in the banking sectors of EU countries, we constructed an econometric models based on panel data.

[12] It should be noted that pVAR models are estimated in packets using the GMM estimator [Holtz-Eakin, Newey, and Rosen, 1988].

It should be noted that the FinTech develops independently from the banking sector and the banking sector is a major implementation field for FinTech solutions. Therefore, in the model, we considered the variables determining new technologies inside the banking sector, outside the banking sector and the variables relating to the fintech sector[13] (see, Pawłowska, 2022). The panel data included annual data at the national level of 28 EU economies. Data in the panel covered the macroeconomic situation (e.g., GDP growth) in individual EU economies, the level of concentration in individual banking sectors, the situation in the banking sector and bank performance, e-banking and the FinTech sector. Data for the panel came from the European Central Bank and Eurostat. It should be noted that FinTech solutions emerged in the last 5–6 years, so analysing them in earlier periods is difficult.

Additionally, the responses to various disturbances of the model described by Equation (3) are compared by implementing the IRF on the panel data of EU countries for three types of loans: loans for household, lending to non-financial corporations and total loans (loans). Their values differ among groups of EU countries and change over time to such an extent that they may affect the mechanism of connections between the real and financial spheres. Their impact on credit growth at various levels of banking sector concentration is presented only for the CR5 index, but related results are obtained for the HHI. Figure 5 in the appendix illustrates the course of the IRF for three types of with 95% confidence intervals for EU banks. The results show that the values of the response function to the demand impulse are not significant in the case of corporate loans, while the function follows a similar course in the case of mortgage and consumer loans.

We also take into account variables from payment statistics from the ECB were adopted as variables describing the new technology within the banking sector country c in year t: share of the number of individuals using the internet for online banking in the population (Internet).In this model we take into account new FinTech variables from the study: Cornelli, Doerr, Franco, & Frost, (2021).

Spurious or nonsense regression is always an aftermath effect of time series data with a unit root problem. To check stationarity, Fisher-type unit-root tests were used. Additionally, the responses to various disturbances of the model described by Equation (2) are compared by implementing the IRF on the panel data of EU countries. Their values differ among groups of

[13] The following variables derived from payment statistics from the ECB were adopted as variables describing the new technology within the banking sector country *c* in year *t*: share of the number of individuals using the internet for online banking in the population (*Internet*); ATM's located in the country (*ATM)*; The following concentration ratios derived from ECB statistics have been adopted as indicators of market structure for country *c* in year *t*: *CR5* and *HHI*.

EU-28 countries and change over time to such an extent that they may affect the mechanism of connections between the real and financial spheres.

The COVID-19 pandemic can be said to have caused even faster development of digital technologies and the FinTech sector. The pandemic also highlighted both the progress and the shortcomings of digital payment systems. Thus, new players in the FinTech sector bring many benefits to their customers and the entire financial sector but generate new types of risk. Therefore, that as the sector develops, it will affect the stability of the financial system and will pose more and more challenges for traditional banks and regulators.

It should be stressed, that in the future the behaviour of traditional banks in the lending market towards FinTech companies will take the form of the so-called coopetition, i.e., a situation where enterprises compete and cooperate with each other at the same time.

Conclusion

The 2008 financial crisis demonstrated how extremely important it is to deepen knowledge on the relations between the financial sector and the real economy This was confirmed by the events related to the collapse of banks in 2023. Therefore, the concept of macroprudential policy as a response to the need to strengthen the stability of the financial system has also become a subject of very intense international debate. It should be noted that a vivid scientific debate on the role of financial market imperfections in accounting for its malfunctions is still taking place. Two-way interactions between the financial sector and the real economy on the one hand hamper the drawing of clear conclusions, but also inspire further studies and the development of econometric methods. It seems that, just like the global financial crisis of 2008, the spread of the COVID-19 pandemic and the current crisis of 2023 will also foster further research on these relationships.

In addition, the new FinTech players blur the lines between the financial sector and the real economy. The operations of FinTech firms are fuelled by a number of demand and supply factors. The studies at hand show that unsatisfied demand for financial services (including financial exclusion) is an extraordinarily strong factor driving the FinTech market. It should be noted that faster growth of the FinTech sector took place in countries in which financial services were expensive and inaccessible for many customers of the market of bank and non-bank (including payday) lending (Philippon 2019). Undoubtedly, technical changes have a significant impact on the shape of traditional banks. By entering the area of activity previously reserved for banks, FinTech companies exert a huge influence on the financial services sector. Traditional banks adapt their business models to digital technologies, which

has significant consequences for the future of the entire financial sector. Traditional banks try to respond to FinTech competition. On the one hand, the new players take advantage of the banks' weaknesses, e.g., bank customers' perceiving bank services as costly, as well as slow processing of some transactions. On the other hand, banks have potential to invest in the development of innovative technologies based on the infrastructure in place. However, offering the same technology may not always suffice to retain customers, who is why banks often resort to branding and they sometimes activate their own versions of a "digital bank" (cf. Carletti et al. 2020). The recent events such (the COVID pandemic and geopolitical crisis) had only accelerated this process.

This paper finds based on into two models using simple panel data regression and the interacted panel vector autoregression model this paper confirms the impact of FinTech on credit grow. Finally, based on the quantitative analysis this paper confirms that innovative technology has had an impact on bank lending especially our findings confirm the leading role of loans for households in the use of new digital technologies.

In today's rapidly changing economic reality a greater emphasis is put on the relations between economic growth, respect for the environment and quality of life, which influences new financial products. What is more, the financial sector currently supports sustainable development policies. The growth of sustainable finance driven by a combination of market forces and decision makers' activity aims to improve data disclosure and risk analysis associated with climate change. It may also gain support from digital technologies. In today's rapidly changing economic reality a greater emphasis is put on the respect for the environment and quality of life, which influences new financial products which are more socially responsible introduced by both new providers and traditional banks.

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Annex

Table A1: Construction of variables and summary statistics of EU-28 of banking sectors data and real economy data. This table provides summary statistics (mean and standard deviation (SD)) for all variables in the model 1 and 2. Data are observed yearly from are observed yearly from 2010–2021.

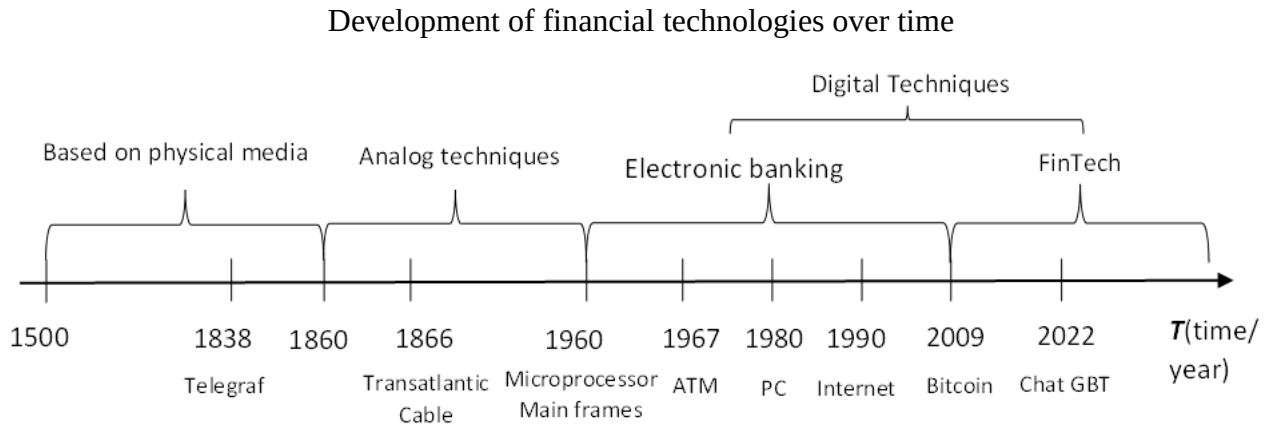
Variable names	Definitions	Nu. of Obser.	Mean	Std. Dev.	MIN	MAX
Loans_GDP	Loans to GDP %	336	12.90705	12.201	0.522	50.905
Loans_PC	Loans per capita	336	0.065	.0359	0.0117	0.1802
Loans_H	%annual change in household loans (in euro)	335	0.0343	0.06671	-0.33306	0.25603
Loans_NFC	%annual change in corporate loans (in euro)	334	0.0017	0.07280	-0.36293	0.31026
Loans_T	%annual change in total loans (in euro)	336	-0.0157	0.097918	-0.43841	0.6125
CR5	Share of the 5 largest credit institutions in total assets[14]	286	62.0285	18.1816	26.18	97.28
HHI	Herfindahl-Hirschman index is the sum of the squares of the market share of individual banks for assets[15]	286	0.13645	0.156726	0.0245	1.3
ROA	Return on assets	289	0.6116	0.782862	-2.55	3.04
ROE	Return on equity	289	7.1482	8.3403	-29.28	24.07
FinTech1	FinTech equity financing in relation to GDP; data from the study: Cornelli, Doerr, Franco, & Frost (2021), pp. 31–43.	286	48.44	10.6071	2	90
FinTech2	Number of transactions in the FinTech sector in relation to GDP; data from the study: Cornelli, Doerr, Franco, & Frost (2021), pp. 31–43.	292	60.7971	15.7902	24	88
GDPpc	The gross domestic product per capita	286	35023.6	22098.2	6812.41	118823.6
GDP	The gross domestic product growth rate yoy	286	2.975	2.78129	-1.4	25.1
ATM	Number of Automated Teller Machines (ATMs)	224	41915.2	32002.9	196	86767
Internet1	Internet banking (% of individuals)	224	48.44	16.84	2	90
Internet2	Individuals using the Internet	278	78.11876	11.7297	39.93	98.14
Mobile	number of mobile phone subscriptions per 100 people	281	124.375	15.625	91.9	172.12
Server	Number of secure servers	295	13511.7	29888.65	39.02	277133.7

Source: own calculations based on ECB, Eurostat data. This table provides summary statistics (mean and standard deviation (Std. Dev.) for all variables in the model. Data concerning FinTech are observed yearly from 2010–2020, data are missing for Romania and Croatia (see: Cornelli, Doerr, Franco, Frost, 2021).

[14] CR_k denotes the market share of the *k* largest banks in gross loans, net assets and deposits in assets.

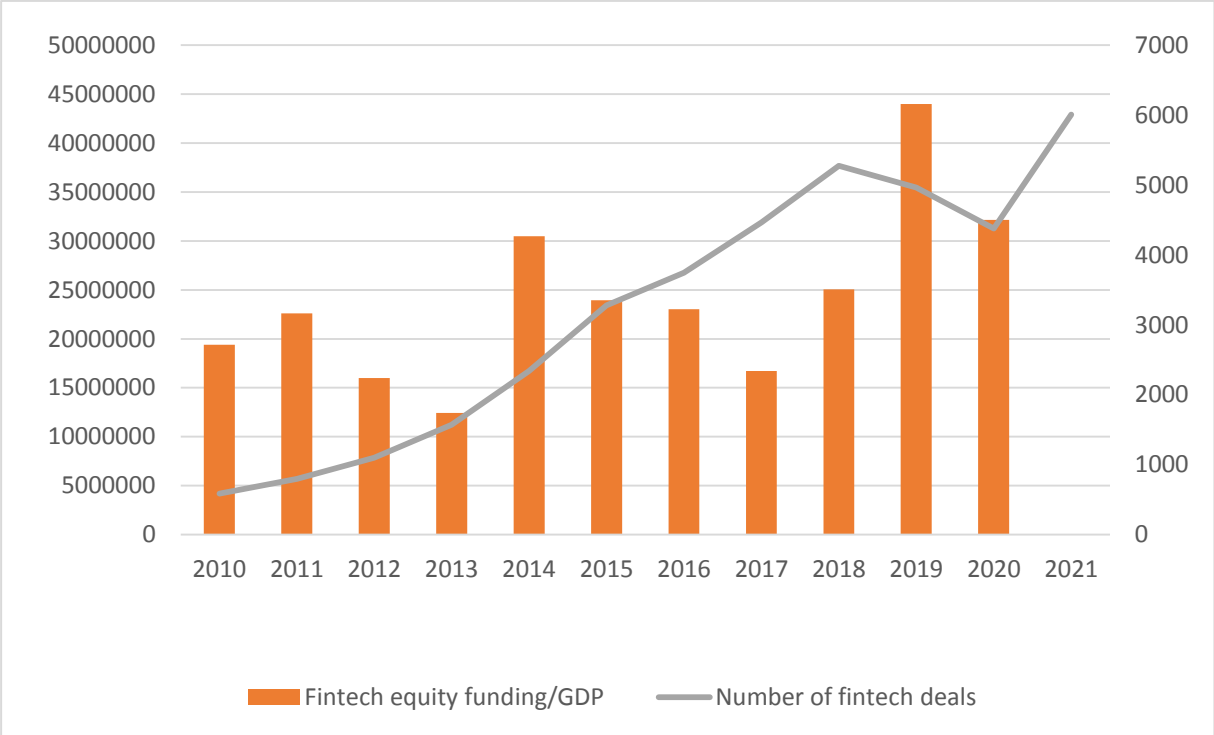
[15] The Herfindahl-Hirschman Index (HHI) is calculated as the sum of the squares of each commercial bank's market share (e.g., in net assets). Index values range from 0 to 1, with higher index values indicating higher market concentration.

Fig 1. Financial Technologies over Time



Source: own elaboration based on Nicoteltti, 2017 pp. 14-16, Alt, Beck & Smith, 2018, p. 236.

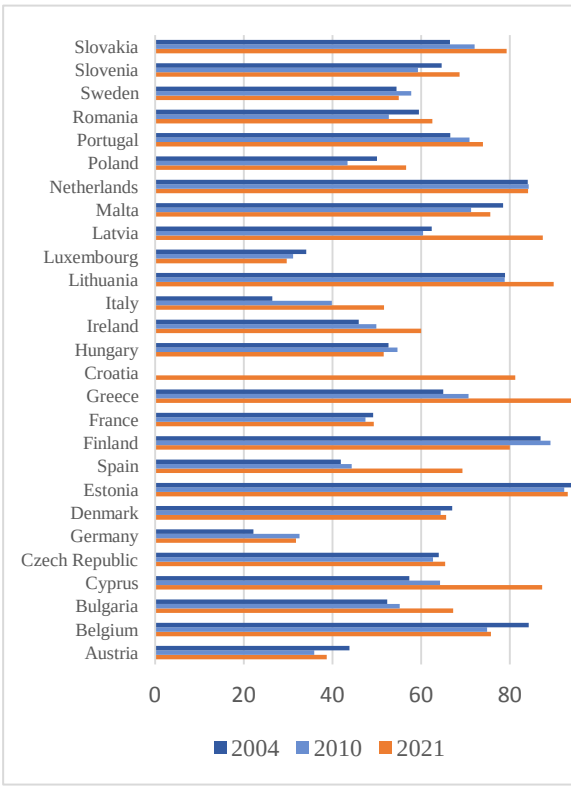
Fig 2. Fintech in EU



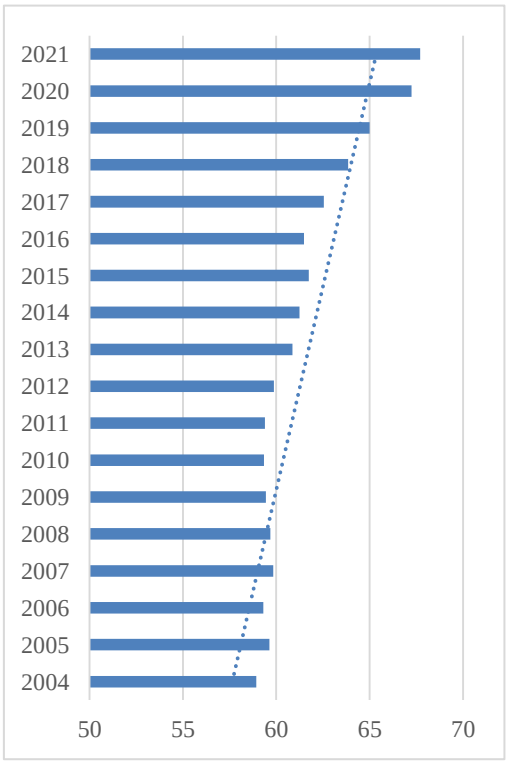
Source: own calculations based on Cornelli, Doerr, Franco, & Frost (2021), pp. 31–43.

Fig. 3. Banking Concentration in EU-28 (%)

A: EU-28 in 2021, 2010 and 2004 (%)



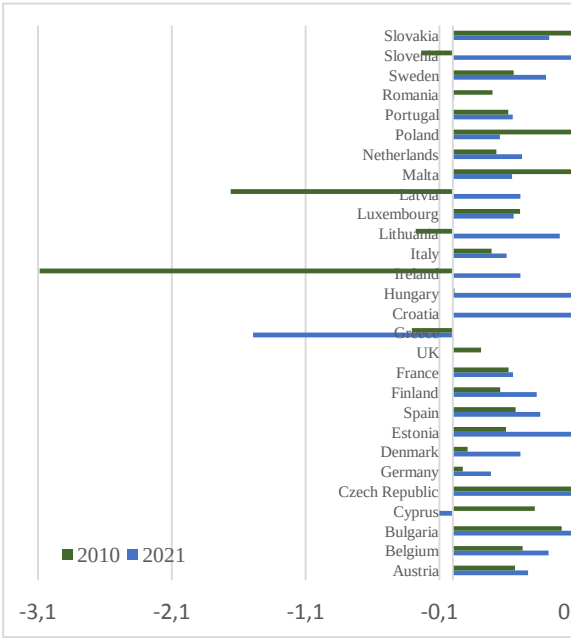
B: Average CR5 (%)



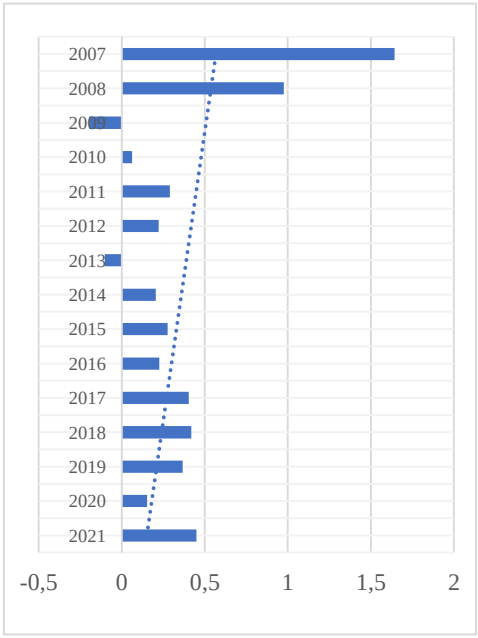
Source: ECB and own calculations on the basis of ECB data.

Figure 4. ROA of the EU Banking Sectors in 2019 (%)

EU-28 in 2021 and 2010 (%)



B: Average ROA (%)



Source: own calculations on the basis of ECB data.

Table 2. Empirical Results for the model for the period 2010-2021 (MFE)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	*g_loans*	*l_perc*	*l_gdp*	*l_hou*	*l_nfc*
Fintech	0.041	0.321	0.004	0.030	-0.028
	(0.067)	(0.692)	(0.005)	(0.026)	(0.047)
ATM	-0.000	0.013***	-0.000	0.000	-0.000
	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)
CR5	-0.001*	-0.037	0.000	-0.000	-0.001
	(0.001)	(0.028)	(0.000)	(0.000)	(0.001)
ROA	-0.013	-0.399	-0.004**	0.019**	0.015
	(0.019)	(0.268)	(0.002)	(0.009)	(0.016)
Mobile	-0.000	-0.026*	-0.000	0.001**	0.001*
	(0.001)	(0.014)	(0.000)	(0.000)	(0.001)
INTER	0.001	0.009	-0.000**	0.000	0.000
	(0.001)	(0.033)	(0.000)	(0.000)	(0.001)
lgdpperc	-0.032	5.586***			
	(0.027)	(1.908)			
lgdp			-0.005	-0.004	0.011
			(0.009)	(0.019)	(0.027)
COV	-0.132**	0.509	0.002	-0.008	0.006
	(0.056)	(0.546)	(0.004)	(0.021)	(0.038)
Constant	0.383	-39.834**	0.117	-0.065	-0.234
	(0.296)	(19.132)	(0.087)	(0.199)	(0.288)
Observations	102	102	107	99	99
Number of id	26	26	26	26	26

Source: own calculations. Standard errors in parentheses, ∗∗∗p < 0.01, ∗∗p < 0.05, ∗p < 0.1.

Table 3: Empirical Results for the model for the period 2010-2021 (OLS)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	*g_loans*	*l_hou*	*l_nfc*	*l_hou*	*l_nfc*
CR5	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
ROA	0.008	0.003	0.008**	0.003	0.008**
	(0.005)	(0.003)	(0.004)	(0.003)	(0.004)
ATM	-0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lserver	0.023***	0.005*	0.005	0.005*	0.005
	(0.004)	(0.002)	(0.003)	(0.002)	(0.003)
INTER	-0.001	0.000	0.000	0.000	0.000
	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
lgdpperc	0.019	0.020	0.015		
	(0.021)	(0.017)	(0.020)		
lgdp				0.020	0.015
				(0.017)	(0.020)
COV	0.059*	0.026	0.047**	0.026	0.047**
	(0.031)	(0.016)	(0.023)	(0.016)	(0.023)
Constant	-0.364*	-0.223	-0.202	-0.223	-0.202
	(0.218)	(0.180)	(0.210)	(0.180)	(0.210)
Observations	224	224	224	224	224
Number of id	26	26	26	26	26

Source: own calculations. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Empirical Results for the model for the period 2010-2021 (FE)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	*g_loans*	*l_hou*	*l_nfc*	*l_hou*	*l_nfc*
FinTech	0.037	1.426	0.003	0.037	-0.038
	(0.067)	(0.949)	(0.005)	(0.026)	(0.048)
CR5	-0.001**	-0.101***	0.000*	-0.000	-0.001
	(0.001)	(0.035)	(0.000)	(0.000)	(0.001)
ROA	-0.015	-0.360	-0.004**	0.020**	0.011
	(0.018)	(0.377)	(0.002)	(0.009)	(0.015)
Mobile	-0.000	-0.047**	-0.000	0.001**	0.001*
	(0.001)	(0.019)	(0.000)	(0.000)	(0.001)
INTER	0.001	-0.035	-0.000**	0.000	0.001
	(0.001)	(0.043)	(0.000)	(0.000)	(0.001)
lgdpperc	-0.040	9.089***	-0.005		
	(0.025)	(2.260)	(0.009)		
lgdp				0.003	-0.002
				(0.019)	(0.024)
COV	-0.132**	1.130	0.001	-0.006	0.002
	(0.056)	(0.759)	(0.004)	(0.020)	(0.039)
Constant	0.463*	-65.210***	0.115	-0.118	-0.111
	(0.280)	(22.569)	(0.087)	(0.200)	(0.266)
Observations	102	102	107	99	99
Number of id	26	26	26	26	26

Source: own calculations. ***p < 0.01, **p < 0.05, *p < 0.1.

Fig. 5. The impulse response function (IRF) for total loans for EU

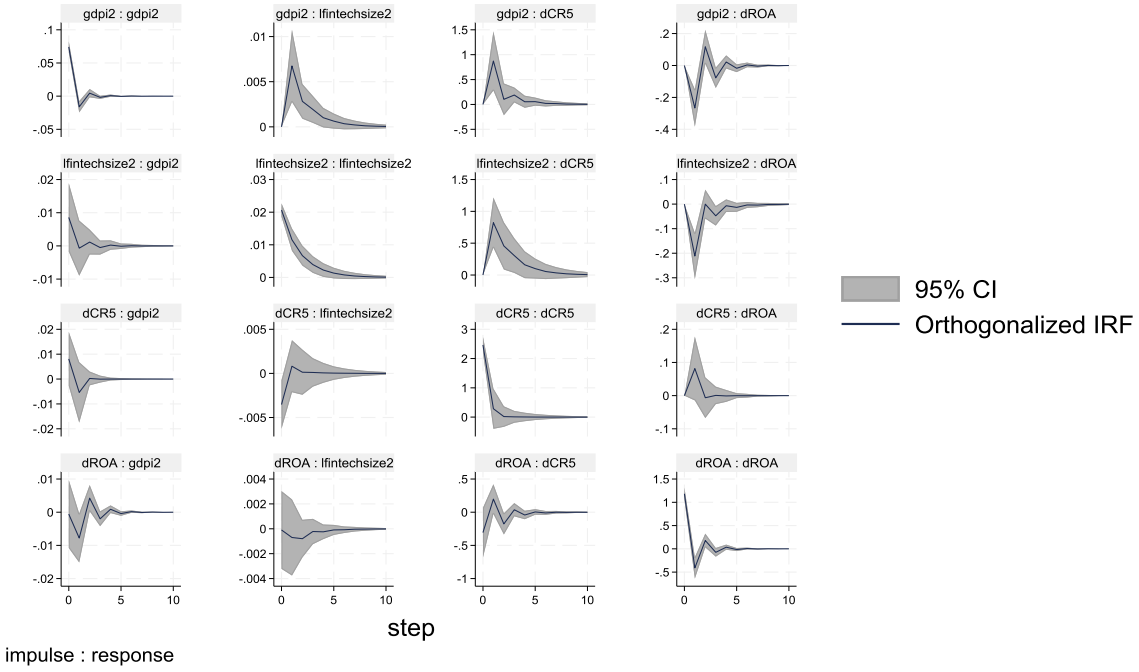
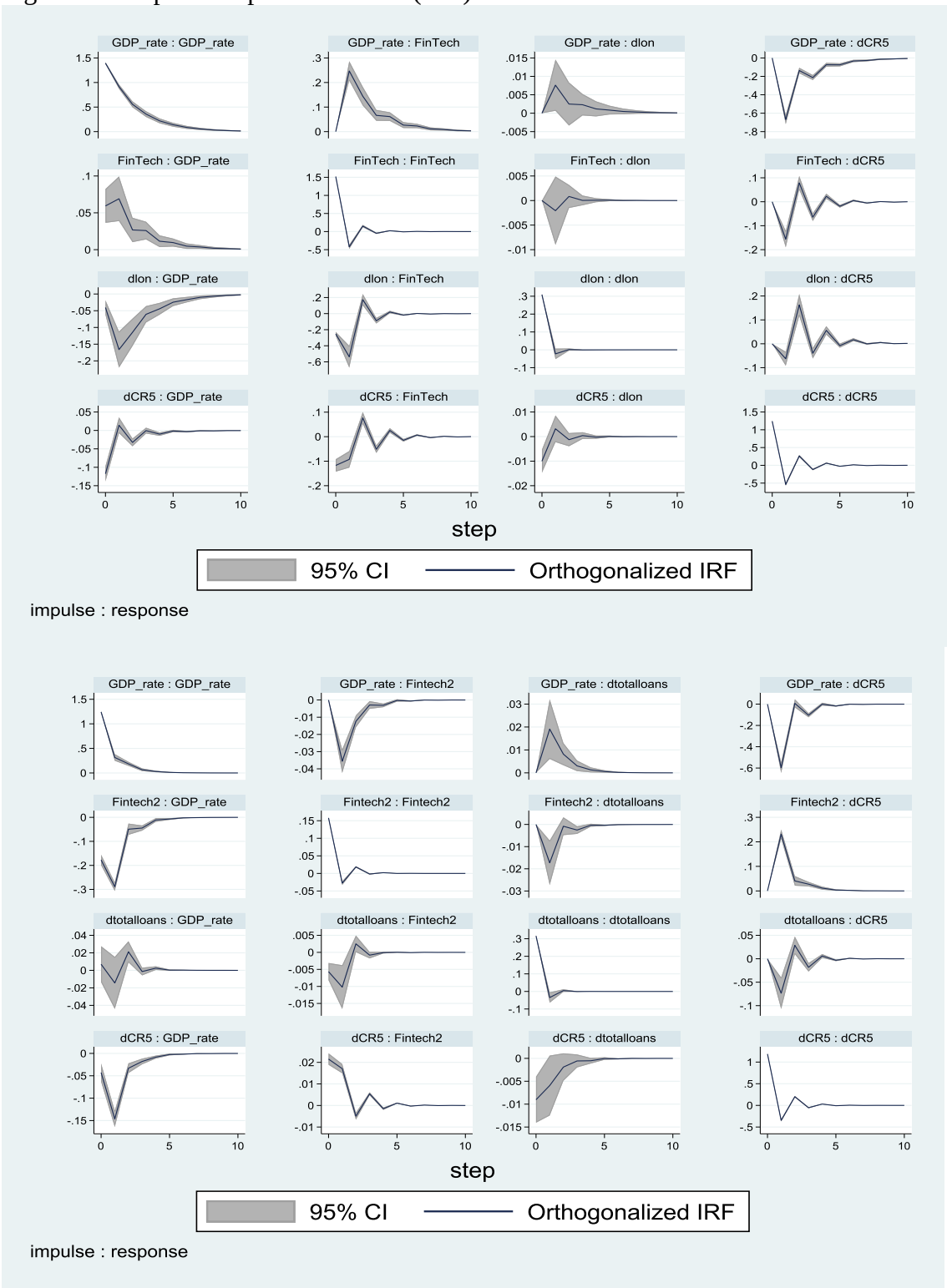


Fig. 6. The impulse response function (IRF) for total loans for EU



Source: own calculations. Data concerning Fintech2 are observed yearly from 2010–2020, data are missing for Romania and Croatia (see: Cornelli, Doerr, Franco, Frost, (2021).