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$$\frac{n!}{(n-1)!} p^{m-1} (1-p)^{n-m} = p \sum_{\ell=0}^{n-1} \frac{\ell+1}{n} \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p \frac{n-1}{n} \sum_{\ell=0}^{n-1} \left[\frac{\ell}{n-1} + \frac{1}{n-1} \right] \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p^2 \frac{n-1}{n} +$$

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Institute of Economic Studies,
Faculty of Social Sciences,
Charles University in Prague

[UK FSV – IES]

Opletalova 26
CZ-110 00, Prague
E-mail : ies@fsv.cuni.cz
<http://ies.fsv.cuni.cz>

Institut ekonomických studií
Fakulta sociálních věd
Univerzita Karlova v Praze

Opletalova 26
110 00 Praha 1

E-mail : ies@fsv.cuni.cz
<http://ies.fsv.cuni.cz>

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Regulatory Stress Tests and Bank Responses: Heterogeneous Treatment Effect in Dynamic Settings

Karel Janda^{a,b}
Oleg Kravtsov^a

^aDepartment of Banking and Insurance, University of Economics, Prague, W. Churchilla 4, 13067 Praha 3, Czech Republic

^bInstitute of Economic Studies, Faculty of Social Sciences, Charles University Opletalova 26, 110 00, Prague, Czech Republic
Email (corresponding author): Karel-Janda@seznam.cz

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Abstract:

This paper investigates the impact of regulatory stress test framework in the European Union on the banks conduct and portfolio adjustments. Our findings suggest that the banks subject to regulatory stress testing tend to structure their portfolios with lower risk density. However this does not affect the dynamic of realized risk that is measured by the proportion of non-performing exposure in portfolios. We argue that the regulatory stress testing can incentivize banks to altering a mix of assets in their balance sheets towards less capital-intensive areas, and thus creating concerns on the systemic concentration of risks in certain type of assets. The evidence from our analysis indicate that the stress-tested banks do not engage in moral hazard behaviour i.e. increasing risk in portfolio or experiencing excessive loan growth. Therefore we show that this regulatory tool successfully fulfils its objective of promoting prudent risk management practices.

JEL: G20, G21, G28

Keywords: Regulatory stress test, capital regulation, heterogeneous treatment effect, event study, instrumental variable

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1 Introduction

In the post-crisis period, a stress testing has emerged as one of the major tool used by regulators to assess the resilience of individual institutions and financial systems to the economic shocks. Since 2010, the Committee of European Banking Supervisors (CEBS) and the European Banking Authority (EBA) have been conducting a European Union (EU)-wide stress tests of the banking system with an aim to assess the resilience of financial institutions to adverse market developments, as well as to contribute to the overall assessment of systemic risk in the EU financial system. The EBA stress tests are microprudential in nature, since they are conducted in a bottom-up fashion, using methodologies, scenarios and key assumptions for simplification and consistency reasons.

A number of studies indicate that the post-crisis implementation of the regulatory stress tests had a substantial impact on the changes in bank behaviour on the singular institutional level (Acharya et al., 2018; Bassett and Berrospide, 2018; Pierret and Steri, 2019). The forward-looking nature of the stress test exercises that allows to project the amount of the capital required to maintain in the future under the adverse economic conditions naturally leads to a variety of ex-ante responses of the banks. Given the high level of complexity of banking institutions, the diversity of business models and portfolios sensitivities there is a concern about the extent of the impact of banks' adjustments to additional capital requirements and enhanced regulatory scrutiny (Andersen et al., 2019; Bräuning and Fillat, 2019). This paper addresses this issue by exploring in-depth the time-dynamic causal effect of regulatory stress tests on bank's risk behaviour and portfolio choices. From a financial stability perspective, it is crucial to know how the banks react to enhanced scrutiny and adjust their balance sheets over the longer time horizon because this reaction can have considerable impact on other financial intermediaries, thus affecting the real economy.

Specifically, the focus of our article is on the investigation of changes in risk-behaviour and the portfolios associated with EU-wide stress test rounds in 2011, 2014 and 2016. We develop a three-step approach in the econometric framework of the event study and treatment effects analysis. The two-way (unit and time) fixed-effect linear regression has been employed in time-dynamic settings to evaluate the heterogeneous average treatment effect. As a next step, we adopt the structural equations framework with an instrumental variable (IV). The IV is manually constructed on the basis of the publicly available results of EBA regulatory stress test rounds in 2011, 2014, 2016 and methodologies of Acharya et al. (2014); Bassett and Berrospide (2018); Eber and Minoiu (2016).

We find that regulatory stress testing causes a decline of risk density of portfolios, mostly attributable to a decrease in its numerator i.e. risk-weighted assets. Seemingly it does not affect the realized risk that is measured by the proportion of non-performing exposure in portfolios. We argue that regulatory stress testing incentivizes banks to altering a mix of assets in their balance sheets towards less capital-intensive areas, and thus creating concerns on the systemic concentration of risk in certain type of assets. On the other hand, we observe that the stress-tested banks do not engage in moral hazard behaviour i.e. increase risk in portfolio or excessive loan growth, thus stress testing fulfils its objective of promoting prudent risk management practices.

Our contribution to the literature is twofold. Firstly, our study contributes to the banking literature that specifically focuses on investigating the implications of regulatory policies on stress testing and capital requirements for the banking institutions (Ahnert et al., 2018; Bassett and Berrospide, 2018; Calem et al., 2017; Cohen and Scatigna, 2016; Cortés et al., 2018; Goldstein and Sapra, 2014; Goncharenko and Rauf, 2019; Gropp et al., 2018; Mésonnier and Monks, 2014; Pierret and Steri, 2019; Schuermann, 2013; Stádník et al., 2016; Sutorova and Teplý, 2013; Vozková and Teplý, 2018). We extend this literature by providing evidence from statistical analysis based on the alternative identification strategy that allows us to isolate the effects of regulatory stress test from other capital regulations and analyse the heterogeneity of treatment effect in time-dynamic settings. Secondly, our results have important implications for the supervisors since we shed some light on the dynamic of bank behavioural responses to the regulatory scrutiny of stress tests. The insights gained from our ex-post assessment can contribute to the studies on the calibration of scenarios and methodologies of microprudential stress testing, e.g. discussions on the static balance sheet assumption (Budnik et al., 2019; Busch et al., 2017).

The rest of this article is structured as follows: Section 2 reviews the prior literature, institutional background and develops our hypotheses; Section 3 provides details on the dataset and the sample matching strategy; Section 4 elaborates the econometric strategy and describes the methods in detail; Section 5 summarizes the results and implications; Section 6 concludes the study.

2 Related Literature and Institutional Background

2.1 Literature Review

The role of the regulatory stress testing and its impact on financial stability and institutions have attracted recently considerable attention from researchers and policymakers. There are several strands of literature in this context. The first stream of literature is dealing with questions of optimal disclosure and an asymmetric information associated with it. The second one is a significant body of literature that focuses on the reaction of markets and investors to the announcements of the regulatory stress tests events and published results. The studies that investigate the impact of regulatory stress tests on the individual bank's conduct due to the additional capital requirements and stricter supervision are the closest to our analysis.

It is well known that the banks are complex institutions whose assets are difficult to evaluate by external parties, for example, creditors, regulators or other market participants. The benefits of managing the asymmetry information in lending markets are clearly emphasized in seminal works of Campbell and Kracaw (1980); Diamond (1984); Leland and Pyle (1977). Given the high level of information disclosure of the insights into portfolio risk and balance sheets of the financial institutions, there is a number of papers highlighting the concerns about the hidden costs of disclosing banks financial information and stress test results. For example, Goldstein and Sapra (2014) argue that by promoting financial stability and market discipline from a macroprudential perspective, disclosure of stress test results may exacerbate bank-specific inefficiencies by changing the ex-ante incentives of managers. As stress tests become routine, supervisors need to be mindful of potential

disadvantages of detailed disclosure of the results at the bank-specific level. The reduction in risk-sharing opportunities in the interbank market and potential panics among bank creditors and other bank counterparties are important consequences associated with it. Some researchers also point out the issues with the interpretation of published results of stress tests e.g. it might imply as an official endorsement of the health of an institution (Schuermann, 2013) or implicit assurance that regulators would in some way absorb losses in excess of the stress test estimates (Flannery, 2013).

Goncharenko et al. (2018) suggest that the information disclosure lowers the expected risk-adjusted profits for a non-negligible fraction of banks. In their empirical analysis of 2011 and 2014 stress tests, they conclude that the magnitude of this effect depends on the structure of the banking system. Alarmingly, it is more valid for the largest and systemically important institutions. The differences in the level of disclosure between the stress-tested banks and non-stressed ones create the informational asymmetry and impede a market of risk-sharing (Georgescu et al., 2017). This increases volatility on interbank markets and leads to the discrepancy between banks funding costs and their risk profile.

Macroprudential regulations of the financial institutions intend to reduce the risks to the financial system by building-up the capital buffer in system large enough to absorb the losses in adverse economic conditions. Acharya et al. (2014) argue that these regulations force institutions to internalize their contribution to systemic risk. In this respect, there is a vast body of literature dealing with channels of transmissions of the additional capital requirements, regulatory monitoring costs and their implications. Among the primary channels of the transmission are the adjustments in bank's balance sheets or portfolio composition structure (Bräuning and Fillat, 2019). They suggest that while the individual portfolios of the largest US banks have become more diversified, the greater convergence of the portfolios held by these banks may be inadvertently increasing the aggregate banking sector's systemic risk factors. Acharya et al. (2018) investigate the risk-taking behaviour of US banks subject to the regulatory stress tests since the Dodd-Frank Act. Their findings are consistent with the "risk management hypothesis", under which stress-tested banks reduce credit supply, particularly to risky borrowers with the aim of decreasing their credit risk. Also, their findings do not support the "moral hazard hypothesis", according to which these banks expand credit supply especially to risky borrowers that pay high spreads and as a result increase their risk. Acharya et al. (2015) provide an in-depth analysis of how the capital requirements can address moral hazard problems in banking associated risk shifting and managerial under-provision of effort in loan monitoring.

There is a mixed empirical evidence on the impact on lending activities and credit supply. Some researches point out a negative effect on lending activities e.g. Mésonnier and Monks (2014) use the banks' balance sheet data to show that overall loan growth decreased at the banks included in the EBA stress test exercise. They find that forcing a banking group to increase its core tier 1 capital by 1 per cent of risk-weighted assets was associated with a decrease of 1.2 percentage points in credit supplied by banks in the same group over the nine-month period of the capital exercise. Similarly, Gropp et al. (2018) show that banks in the 2011 European Banking Authority's capital exercise increased their capital ratios not by raising their levels of equity, but by reducing

the credit supply. The lending volumes to firms decrease for banks subject to the EBA's 2011 capital exercise relative to those that were not included. As a result, firms more exposed to EBA banks reduce total assets, fixed assets, and have lower sales following the exercise. Eber and Minoiu (2016) using the regression discontinuity approach to EBA's stress testing framework, find that banks adjust to stricter supervision by reducing their leverage, and most of the adjustments stem from shrinking assets rather than from raising equity. In contrast, the findings of Bassett and Berrospide (2018) show that among the stress-tested banks in the US, more capital is associated with higher loan growth. The higher capital implied by supervisory stress tests relative to that suggested by the banks' own models does not appear to unduly restrict loan growth. The studies of Cortés et al. (2018) show that post-crisis stress tests have altered banks' credit supply to small business. The stress-test-affected banks raise interest rates on small business loans and reduce the supply to risky borrowers. Similarly, Pierret and Steri (2018) indicate that stress tests effectively prevent excessive risk-taking by bringing stricter supervision on the investment portfolios of stressed banks. Though, the higher capital requirements are not a substitute for regulatory scrutiny to promote prudent lending. They argue that the correction in regulatory capital charges originating from stress tests effectively reduces risky lending.

A number of empirical papers perform the event studies and document a strong market reaction to the announcement of dates and results of stress tests (Ahnert et al., 2018; Candelon and Sy, 2015; Carboni et al., 2017). Most of the studies indicate that the investors gained valuable information due to the disclosure. For example, Petrella and Resti (2013) suggest that the EBA stress test in 2011 achieved its goal to restore confidence and to curb bank opaqueness by helping investors distinguish between sound and fragile institutions. While comparing the outcomes of the results of EBA stress tests to those from alternative methodology on calculation of capital shortfall (SRISK) that relies on publicly available market data, Acharya et al. (2014) conclude that the continued reliance on regulatory risk-weights in stress tests appears to have left financial sectors undercapitalized. This happened especially during the European sovereign debt crisis, and it likely also provided perverse incentives to build up exposures to low risk-weight assets.

Another stream of literature is related to the discussions on calibration of methodologies of stress tests from macro and microprudential perspective (Andersen et al., 2019; Stádník et al., 2016; Witzany, 2017a). In the EU, EBA stress tests are run under the static balance sheet assumption, in meaning that maturing assets and liabilities are replaced with similar financial instruments, and management actions are restricted, so-called "constrained bottom-up" stress test (European Banking Authority, 2016; European Central Bank, 2019). This methodology does not allow for mitigating management actions, such as changes in the composition and size of the balance sheet. In this view, some researchers perform the stress tests under the alternative assumptions that are acknowledging a broad set of interactions and interdependencies between banks, other market participants, and the real economy e.g. (Budnik et al., 2019; Busch et al., 2017). They highlight the importance of the initial level of bank capital and bank asset quality.

Based on the assessment of the publicly disclosed results for four rounds of stress tests in the US, (Glasserman and Tangirala, 2016) find that the stress testing process has evolved and its outcomes have become more

predictable. Therefore, they are arguably less informative to market participants. They suggest an opportunity to get more information out of the stress tests through the greater diversity in the scenarios to be used.

2.2 Institutional framework of EU-wide stress tests and hypotheses development

The EU-wide stress test is part of the supervisory toolkit used by banking authorities to assess banks' resilience to adverse shocks. It aims to strengthen market discipline and transparency through the publication of consistent and granular data on a bank-by-bank level. The first stress test exercises were conducted in 2010, 2011 on EU level by the Committee of European Banking Supervisors (CEBS). With the introduction of Single Supervisory Mechanism (SSM) in 2014, EU-wide stress test is a second pillar of EBA Comprehensive Assessment (CA) along with the Asset Quality Review (AQR) as the first pillar. The EBA stress test rounds were conducted in 2014, 2016 and 2018.

The regulatory EU-wide bank stress tests are the analyses to assess the capitalization of banks on a forward-looking basis under the economic shocks. They test how the decline in profitability and the quality of the bank's assets under adverse economic conditions translates into a hypothetical loss. The riskiness of the banks' assets increases in the stress scenario, resulting in higher regulatory risk-weights assigned to risky exposures and correspondingly lower the post-stress capital ratios defined as a percentage of risk-weighted assets. The economic scenarios usually cover "baseline" and "adverse" cases, and they are forward-looking over 2-3 years horizon. To assess the capital adequacy of all banks subject to the stress test exercise from 2011, the EBA uses one of the main measures, the capital ratio "Common Equity Tier 1 Ratio" defined as:

$$CET1R_t = \frac{K_t}{RWA_t}, \quad (1)$$

where K_t denotes a Common Equity Tier 1 capital, that consists primarily of the common equity and earnings without considering any additional or hybrid capital. RWA_t is the risk-weighted assets measure at the end of reporting period t .

In essence, supervisory stress tests can be considered as dynamic capital requirements that impose risk-sensitive capital buffers on banks. They account explicitly for expected deterioration stemming from adverse economic conditions. From a theoretical perspective and assuming that capital is a higher cost source of funding than the bank would otherwise employ, risk-sensitive capital requirements create stronger incentives for banks to limit risk-taking activities (Bassett and Berrospide, 2018). Following theoretical and empirical literature that relates the level of capital to optimal investment behaviour by banks, we formulate our hypotheses about the impact of the capital gap or hypothetical extra capital implied from the supervisory stress tests on the banks' conduct. The risk management hypothesis (reduction in credit supply) and the moral hazard hypothesis (increase in credit supply) of stress tests as proposed and tested by (Acharya et al., 2017, 2015; Cohen and Scatigna, 2016). In their study they indicate the channels set forth through which bank capital regulations impact bank risk-taking and lending decisions. These channels are derived under the view that depending on how strong their existing capital positions are, banks may have incentives to reduce or expand their lending or change the portfolio

structure in response to results of their stressed capital position. By formulating the following hypotheses, we focus on the causal effects of regulatory stress tests on banks' risk behaviour and performance from the perspective of actual and targeted capital, that banks could employ or on opposite lack as a result of the supervisory stress tests. The questions we attempt to answer using our identification strategy are:

(i) Does the increased regulatory supervision through the stress testing alter the incentives of bank managers and result in changes in risk behaviour referring to the risk-management or moral hazard hypothesis? Is there any evidence of changes in bank behaviour to observe in response to stricter supervision and additional capital requirements from regulatory stress testing?

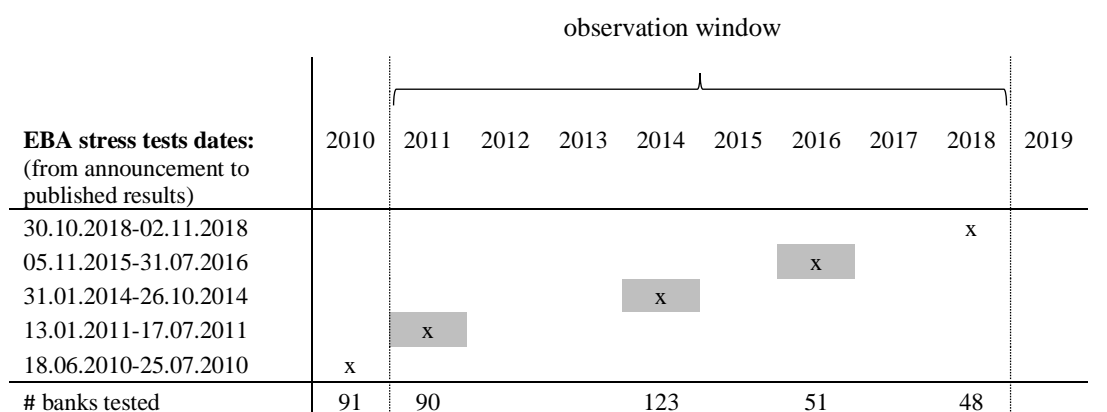
(ii) How different is the time-dynamic, and how strong is the effect of banks specific capital requirements from the regulatory stress tests on the balance sheet and portfolio choices of the group of stress-tested banks in EU-wide stress testing exercise?

3 Dataset Construction and Sample Matching Strategy

The first step of data construction consists of a mapping of individual banks that participated in the EU-wide stress test rounds in 2011, 2014 and 2016. The banks from this sample belong to the treated group and will hereon be referred to as “stress-tested” banks. While the other banks that never participated in regulatory stress test before, belong to the control group and are named as “non-stressed banks”.

For compiling the treated group, we use the published results of stress tests performed in 2011 by the CEBS as well as the 2014 and 2016 stress tests conducted by the EBA. The financial institutions are located in the EU and EEA countries with Single Supervision Mechanism and the Denmark, Norway, Sweden and the UK. The number of banks that participated in separate stress tests were 90 in 2011, 123 in 2014 and 51 in 2016. The results of the regulatory stress test performed by CEBS in 2010, were excluded from our study, because the methodology of the stress test and metrics of results deviate from those used in other stress tests. Thus, they could distort the results of the analysis on the individual bank level. Naturally, we also do not consider the results of 2018 stress test. Because of the forward-looking metrics the 2018 stress tests are not suitable for our econometric approach i.e. comparison of ex-post results with historical data. Figure 1 depicts the timeline of stress tests and observational window, as well as the statistics on our participating banks.

Figure 1. EU-wide stress tests timeline and our sample



| | | | | | | | | | | | | |
|------------------------|--|-----|--|----|--|-----|--|----|--|-----|--|-------|
| of which in our sample | | n/a | | 71 | | 111 | | 51 | | n/a | | _____ |
|------------------------|--|-----|--|----|--|-----|--|----|--|-----|--|-------|

Figure 1 depicts the timeline of stress tests considered in this study. The observation period is censored to the window of eight years to cover three rounds of stress tests conducted by CEBS and EBA in 2011, 2014 and 2016. We exclude the results of stress tests in 2010 by CEBS, since their metrics is not consistent with others. We do not include the most recent 2018 since they are out of scope i.e. ex-post study. Figure 1 includes the statistics on the number of bank participants in the stress test rounds and in our sample (treated group). All data is taken from the official stress test reports available on the EBA website.

The entire dataset covers the period 2011-2018 and is represented by the balance sheet and risk metrics of the fiscal year-end (that is a calendar year-end). The period is censored to the window of 8 years from the first declared regulatory stress test exercises until the year 2018. This time horizon, in our view, captures both short term and long term effects on the adjustment in strategies of banks. Our underlying hypothesis is that the effect from enhanced regulatory scrutiny of the stress test is not static and evolving over the time horizon e.g. from stronger effect during the first rounds to weaker effect of the last rounds. This serves as a basic assumption for our identification strategy discussed later in the paper.

As a next step, we merge by name the financial institutions which are a part of EU-wide stress tests (treated group) with financial data obtained from the database Orbis BankFocus. Similarly, the sample of the control observations is obtained from the database Orbis BankFocus. The financial data are further enhanced by manually extracted financials from annual reports and calculations to fill in the gaps in the data pool. For the financial data from database, we apply an economic filter to include the commercial and savings bank institutions, and to sort out the non-bank financial institutions (e.g. asset management, clearinghouses, etc), or institutions that fall under the category “bad banks” (e.g. Heta Asset Resolution AG). The dataset has been refined by excluding the governmental entities e.g. National Bank of Greece, and by uniting some of the separate entities belonging to the same holding e.g. Raiffeisen Group under the single entity to observe the dynamics over the three waves of stress test.

The EU-wide regulatory stress tests were run at the highest level of consolidation, thus we exclude the largest subsidiaries of multinational banking group, even though they fall under the category of system important institutions on country level. Technically, when we extract the data from Orbis BankFocus for the compiling data of bank units for the treated and control group, we apply the scope of consolidation filter (C1, C2). By doing a manual check of the data, we find a number of banks that were merged, divested or liquidated over the period 2011-2018. We purge them of our dataset along with the banks reporting substantially missing data or errors, for example, due to changes in the ownership, level of consolidation, etc.

The choice of the control group is critically important for estimating the causal effects to ensure the randomized set-up. Therefore, we need an appropriate matching strategy that allows us to combine it with the average treatment effect and the potential outcome framework. By selecting the units for the control group, we consider: (i) observable bank characteristics for selection into the program; (ii) level of capitalization; (iii) geography of headquarter.

The participation in the EU-wide stress test exercise was not randomly assigned to the banks. The selection into the sample are based on the several criteria, such as the size of the assets of the banking group and highest

ranking for systemically important institutions on national level (more detailed in Appendix Table B). EBA selection criteria result in the fact that the stress-tested banks are being on average larger than non-stressed banks. Therefore, the factor of size has to be taken into account for selecting the control group and of cause by choosing the observable characteristics for bank-specific controls. In our sample, the minimum size of total assets for the banks which participated in the EU-wide stress test in 2011 was approximately 500 million EUR (Colonya, Caixa D'estalvis De Pollensa). This amount serves as a minimum threshold for selecting the banks into the control group.

The stress tests represent the forward-looking capital requirements on a single bank-unit level and in standard practice, these are a part of the internal process of capital targets setting. Thereby, the existing level of capitalization plays a significant role in ex-ante portfolio choice and in setting of the banks' capital targets (Andersen et al., 2019; Camara et al., 2013). In order to capture the single effect of regulatory stress test from other capital regulations and in order not to distort the assessment of average treatment effect, we match the control group by similar level of capitalization to those of the treated group. Technically, we sort out the units of the control group by approximate the same level of capitalization of the treated group i.e. Common Equity Tier 1 ratio with a mean value of 16%. The final result is tested by performing the t-test for the two groups of units, depicted on Panel B in Table 1.

To mitigate concerns that our results are driven by cross-country differences, such as national regulatory interventions or business cycles, for the control group we choose the banks located in similar countries as treated¹. Panel A in Table 1 exhibits the bank characteristics of all banks in the sample, while Panel B reports characteristics of separate groups of treated and non-treated units, and provides the results of t-test on significance in the difference in mean. As a result of all these modifications, we obtain the sample of treated group comprised of 110 stress-tested banks and control group of 332. The full list of the bank in the treated group can be provided upon request.

Table 1. Descriptive statistics of treated (stress-tested) and control (non-stressed) groups in the sample

| Variable | Panel A | | | Panel B | | | | | |
|--|-----------|----------|--------|---------|---------|------------|--------|---------|-----|
| | All banks | | | Treated | Control | t-test | | | |
| | Mean | Std. dev | Median | Mean | Mean | Difference | t-stat | p-value | sig |
| <i>Risk and performance metrics</i> | | | | | | | | | |
| RWATA (risk density) | 0.44 | 0.20 | 0.43 | 0.39 | 0.46 | -0.07 | -7.189 | 0.00 | *** |
| Risk Weighted Assets (log) | 9.08 | 1.74 | 8.51 | 10.46 | 8.63 | 1.83 | 22.591 | 0.00 | *** |
| NPL ratio | 0.07 | 0.09 | 0.03 | 0.09 | 0.06 | 0.03 | 7.923 | 0.00 | *** |
| Loan Volume(log) | 9.33 | 1.94 | 8.81 | 10.77 | 8.80 | 1.97 | 23.276 | 0.00 | *** |
| <i>Bank characteristics</i> | | | | | | | | | |
| CET1 ratio | 0.16 | 0.07 | 0.14 | 0.16 | 0.16 | -0.01 | 0.413 | 0.68 | |
| Capital Adequacy Ratio | 0.18 | 0.07 | 0.17 | 0.18 | 0.18 | 0.00 | -0.363 | 0.71 | |
| Size (log TA) | 9.45 | 1.65 | 9.34 | 11.40 | 9.45 | 1.95 | 23.249 | 0.00 | *** |
| Liquidity Ratio | 0.20 | 0.16 | 0.14 | 0.17 | 0.20 | -0.03 | -5.847 | 0.00 | *** |
| Funding Ratio | 0.75 | 0.24 | 0.83 | 0.71 | 0.75 | -0.04 | -4.934 | 0.02 | *** |
| Cost-to-income ratio | 0.65 | 0.33 | 0.64 | 0.62 | 0.65 | -0.03 | -2.144 | 0.03 | *** |

¹ The treated group comprises of 110 banking institutions from the following countries: AT, BE, CY, DE, DK, ES, FI, FR, GR, HU, IE, IT, LU, LV, MT, NL, NO, PL, PT, SE, SI and UK

| | | | | | | | | | |
|----------------------------|------|------|------|------|------|-------|--------|------|-----|
| Net Interest Margin | 2.02 | 2.76 | 1.56 | 1.56 | 2.02 | -0.46 | -4.142 | 0.00 | *** |
| Total number of bank units | 442 | | | 110 | 332 | | | | |

3.1 Variables and Descriptive statistics

Outcome variables of risk and performance

The outcome variable of our interest are the risk indicators that are commonly used as measures of portfolio riskiness: the annual change in the ratio of the risk-weighted assets to total assets (RWATA) and the annual change in non-performing loans to total portfolio ratio (NPL) (Berger and Bouwman, 2012; Camara et al., 2013; Janda and Kravtsov, 2018; Jeitschko and Jeung, 2006; Těplý et al., 2015). RWATA shows the proportion of risky assets in portfolio, but it may also reflect the manager’s choice and strategy with respect to the asset mix in the portfolio. . The second dependent variable (Δ NPL) is an annual change in the ratio of non-performing loans to the total loans on the balance sheet. Our third dependent variable (Δ LOAN) denotes the annual change in loan volumes and captures the effect on the banks’ performance. It describes the portfolio growth and can be analysed in the context of applied risk indicators. For example, the changes in loan growth are associated with standard banking operations and may reduce the NPLs ratio, but an abnormal growth rate would indicate moral hazard problems (Zhang et al., 2016).

Instrumental Variable

To separate the single effect of regulatory stress testing and to allow for the possibility of making causal inferences with our observational data, we construct the alternative exogenous measure “buffer” (BUF) that serves as an instrumental variable (IV)² and is employed in structural and reduced regression models. It serves several roles: (i) within the group of the stress-tested banks “treated” (Methods 1) as a predictive measure to evaluate the ex-ante responses and test on pre-trends factor; (ii) then as interaction term in the regression covariates adjusted DID models (Method 2), and by identification of the causal effects with IV approach in (Method 3). In this Section, we provide a technical description and the underlining logic of the calculations of the measure. The conceptual fit to the identification strategy for assessment of causal effects with the IV and justification why measure BUF qualifies to the criteria of instrumental variable are presented in the relevant methodological description of the econometric settings of Method 3.

According to the EBA stress test methodology, the bank’s capital is supposed to absorb the projected losses under two stress scenarios: baseline and adverse. Therefore, there are minimum thresholds of capital i.e. Common Equity Tier 1 ratio (CET1R) to be reached under both scenarios. Under the baseline scenario, banks were required to maintain a minimum CET1 ratio of 8% and in case of the adverse scenario a minimum CET1 ratio of 5-5.5%³ that is also referred to as “hurdle rate” in EBA stress test methodology (see details on the stress

² Instrumental Variable (IV), instrument and measure BUF are used interchangeably throughout the article.

³ By calculations of the buffer for the adverse scenario, we use the hurdle rate (*k*) CET1Ratio=5% for the period 2011-15 and CET1Ratio=5.5% over period 2016-17 in line with the methodologies of EBA stress tests 2011 and 2014. EBA stress test 2016 does not explicitly refer to any hurdle rate, so we apply as benchmark 5.5%.

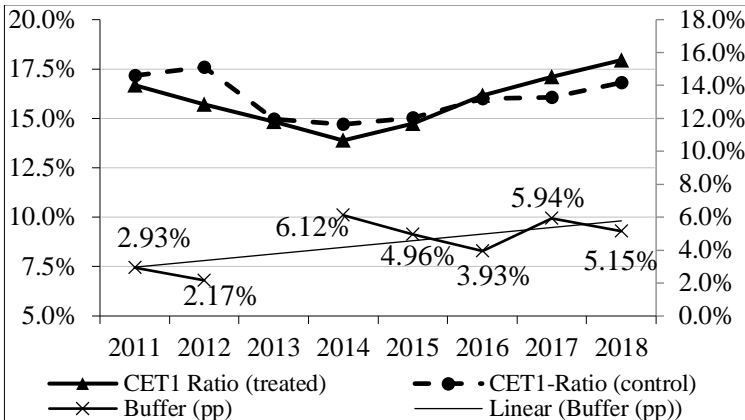
tests in Appendix Table B). Even though from 2016 the hurdle rate is not explicitly referred to in the published results of EBA stress test rounds, we believe that the meaning of it as the benchmark remains the same as before. Besides, the hurdle rate is equivalent to existing minimum capital requirements on CET1 capital.

In essence, the measure buffer (BUF) indicates the strength of additional economic capital available (after the hypothetical economic shock) in comparison to actual CET1 capital. Technically, we calculate the buffer as capital surplus or gap of capital in percentage points needed to pass the minimum regulatory threshold (hurdle rate k) under the baseline or adverse economic scenario of the stress test (Acharya et al., 2014; Bassett and Berrospide, 2018; Eber and Minoiu, 2016):

$$BUF_{it} = \min\{CET1 R_{it}^{baseline} - k^{baseline}, CET1 R_{it}^{adverse} - k^{adverse}\}, \quad (2)$$

The buffer also can be interpreted as an extra capital that each bank can employ as a result of the supervisory stress tests usually more stringent than their own assessment based on the internal stress test models. Those banks that have a value of buffer around zero or minus (i.e. having a capital gap) failed and those banks with higher buffer (as approximation value ≥ 0.01) passed the stress test exercise. Figure 2 shows historical CET1 ratios and corresponding buffer values, while more detailed descriptive statistics, distributional characteristics and data mapping of instrumental variable are presented in Appendix Table D.

Fig. 2: CET1 ratios and measure BUF for the period 2011-2018



Note: in Figure 2, we report average CET1 ratios for both treated and control group after samples matching.

In line with our identification strategy, we consider the observation window that covers a period from 2011 to 2018. It includes three round of stress tests and fitted within the timeline of the instrumental variable (the data mapping and statistics of the instrumental variable exhibited in Appendix Table D). CEBS stress test conducted in 2010 has a methodology and metrics which are not consistent with subsequent stress test rounds, therefore, we don't consider it in our analysis. The proposed methodology of measure calculation causes an overlap in the data of buffer for the year 2016 since both stress tests in 2014 and 2016 have a three-year horizon. Whereby we solve it by taking the conservative stance, similar to the risk management in practice and choose minimum values from two stressed capital ratios. Moreover, the results of the stress test round in 2011 have a two-year horizon, effectively it leads to a gap in the estimation of the values of IV buffer for the year 2013. As a solution

to this problem, we control the time fixed effects by including the full set of the time dummies corresponding to the years of estimates of the buffer values i.e. excluding the year 2013 (only in the models with IV).

Observable bank characteristics (Controls)

The participation in EU-wide stress tests exercises were assigned according to the size of assets on the single bank unit and also on the national level to cover the total assets of 50% of country banking sector (see details in Appendix Table A). The explicit selection rule based on bank size implies that selection into the regulatory stress test exercise was based on observable characteristics. We exploit this exogenous variation in the bank selection rule for the selection of relevant observable covariates of the treated and control group. These matching covariates capture potential differences also associated with the size of assets, such as business model and efficiency, funding and liquidity strategies. Upon the knowledge of observable characteristics and excluding the possibility of self-selection into the program, we restore the randomization in “non-experimental” design (Wooldridge, 2012).

The business model, efficiency and performance are represented by ratios of net interest margin (NIM) and cost to income ratio (COST) (Kuc and Teplý, 2015; Teplý et al., 2015). NIM reveals the amount of money that a bank is earning in interest on loans compared to the amount it is paying in interest on deposits, a part of the macroeconomic factor such as interest rates, net interest margin varies among banks depending on their business models. Similarly, the cost-to-income ratio differentiates between institutions emphasising commercial banking and retail activities (Roengpitya et al., 2017). Less efficient banks or institutions with higher non-interest income may have been tempted to take higher risks to offset the loss of return due to the higher capitalization or low-interest environment (Vozková and Teplý, 2018).

The funding and liquidity structure are represented by ratios of customer deposits to total liabilities (DLR) and liquidity ratio (LAR) of liquid assets, such as cash and short-term tradable securities to total assets. The larger institutions tend to have a larger proportion of wholesale funding and with a reference to regulations on LCR, NSFR they are penalized for the dependence on shorter-term funding, therefore the funding and liquidity structure is important characteristics to account for.

The level of capitalization is measured in our analysis by capital adequacy ratio (CAR) that is a ratio of regulatory capital to total risk-weighted assets. Similarly, many of the larger size banks are a subject to additional capital requirements in view of the systematically important institutions, therefore they are required to maintain higher capitalization level e.g. countercyclical capital buffers, systemic risk buffers, etc. These are not a part of the core capital i.e. CET1 ratio and therefore, we consider them as heterogeneous bank capital characteristics.

4 Empirical Strategy

The aim of our analysis is to examine the impact of regulatory scrutiny from the stress testing exercises on the adjustment strategies in portfolio and changes in risk behaviour of the EU banks that were the subject of the

EBA stress test rounds in 2011, 2014 and 2016. By set-up, the supervisory stress tests can be considered as dynamic capital requirements that impose risk-sensitive capital buffers on banks in case of hypothetical adverse economic conditions. The major challenge for us is to identify and to isolate empirically the single effect of EBA stress testing from other policies, mostly the solvency regulations that are ongoing parallel, similar in nature and thus having “direct” and “indirect” effects. Even though, there is no final consensus between theoretical and empirical results about the direct impact of regulatory capital requirements on the bank’s risk, most researches admit a strong link in capital-risk relationship (Aggarwal and Jacques, 2004; Berger and Bouwman, 2012; Besanko and Kanatas, 1996; Furlong and Keeley, 1991; Jeitschko and Jeung, 2006; Lindquist, 2003; Shrieves and Dahl, 1992).

In our sample we also observe the effect of changes in capital on bank risk behaviour. In both groups, the treated and control, it is evident that the increase in capital is associated with a decline in risk-density. In Table 2, the columns (1) and (2) coefficients exhibit the significance between annual changes in capital (CET1) ratio and risk density ratio (RWATA) that is a ratio of risk-weighted assets to total assets. Such effect is mostly attributable to a decrease in risk-weighted assets (RWA) in columns (6) and (7) that can be attributable to a variety of reasons from portfolio optimization, changes in business models, or approach to calculation of risk-weighted assets (both ratios share the component) e.g. from standard to IRB, advanced-IRB, etc. Notably, we observe no impact on the changes in the quality of portfolio measured as a proportion of non-performing exposure to total portfolio, while there is a simultaneous decrease in the loan volumes indicated for both groups. In summary, we have a mixed picture, therefore, our task is to build up our identification strategy that allows, first of all, to isolate the effect of the regulatory stress testing from others, mostly the regulatory capital regulation and policies. Secondly, we have to establish a direct causal link between the regulatory scrutiny from stress tests and the changes in risk behaviour patterns. Finally, we study the heterogeneity of treatment effect in time-dynamics settings that is considering the timing of the events, which in our case are three waves of the regulatory stress tests in 2011, 2014 and 2016.

In existing studies of the impact of regulatory policies, especially with focus on regulatory stress tests, researchers predominantly employ the econometric tools which allow to estimate the causal effects with a help of “two-group two-period” difference-in-difference (DID) estimator e.g. (Berger and Roman, 2017; Gropp et al., 2018; Pierret and Steri, 2018), extended to difference-in-difference-in-difference (DIDID) (Acharya et al., 2018) or by employing the regression discontinuity methods (Eber and Minoiu, 2016). Another group of econometric methods employing the DID set-up for a policy evaluation rely on the assessment of average treatment effect in combination with various types of sample matching strategies, such as propensity score matching e.g. Dvouletý et al. (2019); Dvouletý and Blažková (2018).

Table 2. Effect of capital on risk and performance in the treated and control group

| Dependent Variable Annual Change (in pp or %) | | | | | | | | | |
|---|-----|-----|-----|-----|-----|-----|-----|-----|------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |

| VARIABLES | RWATA Treated | RWATA Control | NPL Treated | NPL Control | RWA Treated | RWA Control | LOAN Treated | LOAN Control | TA Treated | TA Control |
|--------------------|----------------------|----------------------|-------------------|-------------------|----------------------|---------------------|----------------------|--------------------|-------------------|-------------------|
| ΔCETIR | -0.006*** (0.002) | -0.004*** (0.001) | -0.000 (0.001) | -0.000 (0.000) | -0.021*** (0.006) | -0.015** (0.006) | -0.005** (0.002) | -0.006* (0.003) | -0.001 (0.004) | -0.002 (0.002) |
| Constant | 0.338 (0.521) | 0.458*** (0.139) | -0.092 (0.262) | 0.051 (0.075) | -1.233 (0.973) | 0.527 (0.935) | -2.778*** (0.686) | -1.222* (0.642) | 0.050 (0.076) | -0.047 (0.091) |
| Unit FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 547 | 1,497 | 479 | 1,329 | 549 | 1,486 | 547 | 1,510 | 546 | 1,512 |
| R-squared | 0.268 | 0.249 | 0.363 | 0.254 | 0.322 | 0.407 | 0.321 | 0.343 | 0.361 | 0.397 |
| Adj R ² | 0.100 | 0.0545 | 0.213 | 0.0507 | 0.165 | 0.251 | 0.165 | 0.176 | 0.217 | 0.245 |
| F test | 0.000 | 0.000 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. The standard errors are clustered on the bank-unit level to alleviate the heteroscedasticity bias.

To our best knowledge, this study is one of the firsts to analyse the treatment effect of regulatory stress tests by engaging the two-way fixed effect linear regression in time-dynamic settings, secondly by employing the structural equations with instrumental variables for assessment of heterogeneous average treatment effect. Most close to our identification strategy are the group of econometric methods employing the two-way (unit and time) fixed effects regression models with treatment effect in event study settings (Flannery et al., 2017) and the estimators with the instrumental variable for analysis of policies in social science (Cerulli, 2015). The two-way fixed effects parameterization stems from the same parallel trend assumption involved in the two-group two-period DID, but it accommodates considerably more variation in the details of the research design. This advantage is important for our modelling because it is flexible enough to include several interaction terms between the control variables, group's assignment and the variations in treatment timing.

Our identification strategy is also motivated by some studies e.g. (Glasserman and Tangirala, 2016) indicating that the effects of regulatory scrutiny, particularly of regulatory stress test are not static and that they are evolving over the time horizon. The assigned banks are self-learning units and sooner or later adapt to regulatory policies, or in case of the regulatory stress tests, the scenarios become predictive and the responses are more elaborated. If the effect increases or decreases monotonically or linearly, or shows any other complicated time-related pattern, then the strength of the observed effect in a panel study is strongly dependent on the timing of the panel waves i.e. temporal lags (Blossfeld et al., 2019).

A number of recent econometric studies suggest that the standard double-difference approach becomes problematic when the difference between short and long-term time effects exist, and hence leads to spurious estimates (Athey and Imbens, 2018; Callaway and Sant'Anna, 2019; Imai and Kim, 2019a). To address these issues, we adopt three steps approach by employing different but complementary econometric methods that allows us consequently building up our assessment with the possibility of the robustness checks of results simultaneously. Table 3 exhibits the taxonomy of the empirical methods employed in our step by step approach. In practice, we exploit several analytical dimensions within the framework of treatment effect analysis:

(i) *type of specification* that relies on the distinction between structural (simultaneous equations) or reduced form (one equation). In *reduced form* (Methods 1, 2) the outcome is estimated once controlled on the observable characteristics and accounted for a variation in timing of treatment. In *structural form* (Method 3), when the outcome equation and the “selection-in-the program“ treatment equation are separately modelled in a system of simultaneous equations (2SLS);

(ii) *type of sample*: the restricted sample of only treated banks without a control group (Method 1), and the combined sample that includes both treated and control group;

(iii) *type of treatment*: hereby, we distinguish a form of treatment effect, that is a binary or with application of the instrumented variables (IV) in continuous form.

Table 3. Taxonomy of empirical methods

| Methods | Type of specification | | Type of sample | | Type of treatment variable | | Representative studies |
|---|-----------------------|----------------------|---------------------------|--|----------------------------|-----------------------|---|
| | Reduced form | Structural Equations | Restricted (only treated) | Complete Sample (control+ treated group) | Binary | Instrumental variable | |
| 1. Linear two-way (time and unit) fixed effects linear regression | x | | x | | | x | (Camara et al., 2013; Shrieves and Dahl, 1992) |
| 2. Linear two way-fixed effects regression (covariates) adjusted model with treatment effect (binary) | x | | | x | x | | (Abraham and Sun, 2018a; Athey and Imbens, 2018; Borusyal and Jaravel, 2018; Callaway and Sant’ Anna, 2019) |
| 3. Structural equations (2SLS) with instrumental variables | | x | | x | | x | (Angrist and Krueger, 2001; Cerulli, 2015, 2014; Imbens, 2014; Wooldridge, 2010) |

In the first step (Method 1), we employ the two-way (unit and time) fixed effects linear regression to panel data of the restricted dataset (only treated group) that is censored to the observation window covering the treatment period (incl. three waves of stress test rounds 2011, 2014 and 2016) and duration of the data for measure buffer. The restrictions on the treated sample and duration of treatment allows us to test a model specification on the unit and time-specific trends without control group, and to evaluate the appropriateness of fixed effects in comparison to the random. Secondly, we test the model for a fit of predictive measure buffer as potential instrumental variable and examine the observed characteristic of covariates (confounders). We use several outcome variables of risk metrics as for the robustness check. To validate the model specification, we perform the Hausman test for fixed over random effects.

In the second step (Method 2), the treatment effect is estimated by employing the adjusted DID estimator in a form of linear two-way (unit and time) fixed effects regression with binary treatment indicator on the combined sample (incl. both control and treated). To account for variation in treatment timing, we implement the so-called “event study” framework and employ the adjusted DID estimator (Abraham and Sun, 2018; Athey and Imbens,

2018; Borusyak and Jaravel, 2018; Callaway and Sant’Anna, 2019). The strategy is to restrict the pre-trends and apply full time-dynamic settings with unit fixed effects for complete sample (control and treated units). Practically, we censor the combined sample to the duration of the group treatment (sample is identical to those in Method 1) and account for the time variation in treatment effect i.e. early or late participants, always or never participated units during the three waves of events, or in our case, the regulatory stress test rounds. The control group that consists of never treated and not yet treated units, provides valid counterfactuals for the group of already treated units. The causal effect of the intervention thus can be captured more precisely by comparing not only two groups, but also considering the multi-timing of treatment. By doing so, we avoid the problem with extrapolation and negative weights that will occur if we employ the standard two-groups two-period DID estimator (Borusyak and Jaravel, 2018). We perform a specification test for heteroskedasticity (White, 1980) to assess the appropriateness of the linearity assumption for the standard two-way fixed effects estimator (Imai and Kim, 2019a) i.e. the equivalence between the standard DID and the two-way fixed effects estimator.

In the third step (Method 3), we estimate the average treatment effect using a system of simultaneous equations in the form of two-stage least squares (2SLS) with the IV and assigned confounders. Here our approach is to use the IV in order to enhance the external validity of regression model by calculating the fitted treatment effect indicator conditionally on the instrumental variable and a set of covariates (observable confounders) from Method 1 and 2. The structural form of simultaneous equations with IV allow to control for observable characteristics and unobserved heterogeneity and to decrease the simultaneity bias of capital-risk relation. For the binary treatment indicator, we employ the Probit-OLS, Probit-2SLS and direct-2SLS estimators along with t-test and Heckman’s correction model as a robustness check. The standard post-estimation tests for qualifying to the IV are performed.

4.2 Reaction of stress-tested banks (treated) to the EU-wide stress tests rounds in 2011, 2014 and 2016 (Method 1)

We start with a simple specification, which is common in the empirical literature on the impact of regulatory capital on risk-taking (Aggarwal and Jacques, 2001; Camara et al., 2013; Shrieves and Dahl, 1992; Matejašák et al., 2009) and performance (Berger and Bouwman, 2012). The standard linear two-way (unit and time fixed) effects regression is employed to the restricted sample “treated” group” i.e. the sample consists of the banks that participated in three rounds of regulatory stress tests. The two-way fixed effects model set-up allows to eliminate bias from unobservables that change over time but are constant over units, and it controls for the factors that differ across units but are constant over time. In addition, the standard errors are clustered at the bank-unit level to alleviate the bias from heteroscedasticity.

In our specification, we employ the variable buffer (BUF) targeting to achieve the next goals. First of all, this measure allows us to distinguish the effect of regulatory stress testing from other policies (mostly on capital regulations) within the sample of stress-tested banks (treated group). If the coefficient of BUF alone or in interaction with changes in CET1 ratio shows statistical significance we are able to pin down the bank's

responses solely stemming from the scrutiny of regulatory stress test. Secondly, we test it on the existence of the pre-trends factor. We check if there are any ex-ante adjustments in risk and portfolio in anticipation of the event. Perhaps banking units began changing their behaviour in response to an expectation that they would be “treated” in the future. The proposed instrumental variable BUF provides a measure to observe such changes in outcome prior to treatment. If we are able to observe the statistical significance on the unit level, we can conclude that there are strong anticipation and pre-trends factor. We anticipate some statistical significance in combination with changes in capital relative to the outcome of our interest. The baseline two-way fixed effects (with unit and time fixed effects) linear regression model is presented in Eq. (3):

$$\Delta Y_{it} = \alpha_i + \delta_t + \beta_1 BUF_{it} + \beta_2 \Delta C_{it} + \beta_3 (\Delta C \cdot BUF)_{it} + \gamma' X_{it} + \varepsilon_{it}, \quad (3)$$

where $\Delta Y_{it} = Y_{it} - Y_{it-1}$, and $\Delta Y_{i,t}$ is the outcome variable of annual changes in the risk profile of units i in the period t . The risk profile is proxied by annual changes in risk metrics RWATA (ratio of risk-weighted assets to total assets) and NPL (proportion of non-performing exposure to total portfolio), LOAN (annual growth in loan volumes). The instrumental variable BUF_{it} is an exogenous measure signifying the surplus/gap of hypothetical capital that is derived from the results of EBA stress tests rounds for participated banks (earlier in this Section we provide detailed rational and calculations logic for this measure).

ΔC_{it} represents annual change in Common Equity Tier 1 capital ratio as: $\Delta C_{it} = CET1R_{it} - CET1R_{it-1}$. We consider the interaction component $\Delta C \cdot BUF$ that allows us to distinguish the single effect of regulatory stress test from other capital-related policies e.g. changes in dividend policy, common equity structure, etc. In the specification, Eq (3) we include a vector X_{it} of bank-specific observable characteristics. The covariates include bank-specific variables measured by the end of fiscal year, namely bank size in natural logarithm of total assets, liquidity and funding ratio, efficiency, level of total capitalization (detailed definitions are in Appendix Table A). At last, we include the α_i as a unit and δ_t the time fixed effect. In standard way ε_{it} is a regular unobserved component.

The results of regression in Table 4 indicate that the regulatory stress is associated with additional capital requirements for the treated banks and has substantial impact on the changes in risk density (RWATA), and results in the decline of risk-weighted assets (RWA) and loan volumes. It is even more evident in the models with interaction with instrumental variable BUF in columns (1), (3) and (4). Notably, we do not observe any pre-trend or anticipation factor, as the coefficients for predictive measure and instrumental variable BUF are not statistically significant in all instances, columns (5-8). Hausman test proves that all specifications, except one, in column (5), are robust in favour of fixed effects over the random.

Table 4. The response and portfolio adjustments of the stress-tested banks (treated group) to the regulatory stress test rounds in 2011, 2014 and 2016

| VARIABLES | Dependent Variables Annual Change | | | | | | | |
|-------------------------------|-----------------------------------|--------------------------|-------------------------|--------------------------|----------------------------|--------------------------|-------------------------|--------------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| | RWATA (Δ in pp) | NPL (Δ in pp) | RWA (Δ in %) | LOAN (Δ in %) | RWATA (Δ in pp) | NPL (Δ in pp) | RWA (Δ in %) | LOAN (Δ in %) |
| Δ CET1R x BUF | -0.047*** (0.015) | 0.001 (0.008) | -0.310*** (0.042) | -0.065* (0.036) | | | | |
| Δ CET1R | | | | | -0.004*** (0.001) | -0.002 (0.001) | -0.014** (0.006) | -0.003 (0.004) |
| BUF | 0.229 (0.214) | 0.042 (0.143) | 0.400 (0.653) | -0.763 (0.497) | 0.261 (0.207) | 0.024 (0.133) | 0.563 (0.693) | -0.726 (0.480) |
| TAllog | -0.072 (0.052) | -0.020 (0.024) | 0.053 (0.123) | 0.186 (0.167) | -0.076 (0.052) | -0.021 (0.022) | 0.053 (0.119) | 0.191 (0.168) |
| LAR | -0.140 (0.107) | -0.088 (0.065) | -0.518 (0.380) | -0.108 (0.215) | -0.162 (0.107) | -0.103 (0.067) | -0.597 (0.386) | -0.126 (0.218) |
| DLR | -0.058 (0.108) | -0.009 (0.051) | 0.211 (0.301) | 0.374* (0.205) | -0.055 (0.111) | -0.000 (0.051) | 0.250 (0.315) | 0.379* (0.205) |
| COST | -0.002 (0.005) | 0.007 (0.006) | -0.028 (0.018) | -0.029* (0.017) | -0.002 (0.006) | 0.008 (0.005) | -0.043* (0.024) | -0.032* (0.018) |
| NIM | -0.029 (0.021) | -0.016 (0.011) | 0.011 (0.048) | 0.037 (0.077) | -0.028 (0.021) | -0.016 (0.010) | 0.007 (0.050) | 0.038 (0.078) |
| CAR | -0.175 (0.167) | 0.049 (0.081) | -1.164*** (0.377) | -0.262 (0.237) | -0.142 (0.162) | 0.095 (0.098) | -1.118*** (0.376) | -0.252 (0.262) |
| Constant | 1.040 (0.676) | 0.271 (0.312) | -0.404 (1.682) | -2.425 (2.221) | 1.080 (0.674) | 0.267 (0.294) | -0.399 (1.645) | -2.488 (2.240) |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 362 | 324 | 368 | 367 | 362 | 324 | 368 | 367 |
| Number of units | 85 | 74 | 86 | 86 | 85 | 74 | 86 | 86 |
| R-squared | 0.186 | 0.200 | 0.290 | 0.055 | 0.191 | 0.217 | 0.236 | 0.052 |
| F test | 0.000 | 0.000 | 0.000 | 0.0521 | 0.000 | 0.000 | 0.000 | 0.194 |
| Hausman's test results | | | | | | | | |
| χ^2 - statistics | 65.69 | 94.40 | 33.02 | 32.27 | 16.87 | 41.71 | 37.39 | 32.36 |
| Prob. Value of χ^2 | 0.0000 | 0.0000 | 0.0112 | 0.0179 | 0.3269 | 0.0002 | 0.0006 | 0.0036 |

Note: Rejection of the null hypothesis implies that the fixed effect model is more suitable than random effect.

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

4.3 Portfolio choice and changes in risk-behaviour due to the regulatory scrutiny of regulatory stress tests - “selection on observables” (Method 2).

The second question we try to answer in our analysis is how the effect of the increased scrutiny from regulatory stress test impacts the risk and portfolio of the group of stress-tested EU banks (treated group) by comparison with other banks that did not participate in regulatory stress test (non-treated)? In other words, we are interested in estimating the average treatment effect on the treated subset of units from the population sample. The analysis of time-dynamics of treatment effect in the case of observable heterogeneity is a subject of our study too.

As a basis, we employ the linear regression (covariates) adjusted model with treatment effects (Angrist and Pischke, 2009; Card and Krueger, 2000; Imbens and Rubin, 2015). We extend it to account for unit and time (two-way) fixed effects and for variation in treatment timing (Abraham and Sun, 2018; Athey and Imbens, 2018; Borusyak and Jaravel, 2018). The two-way fixed effects parameterization stems from the same common trend assumption involved in the two-group two-period DID, but it allows considerably more variation in the details of the research design. The model we propose with adjustments which are in econometric literature also frequently referred to as “event study”, exploits variation in the timing of a unit’s treatment for more robust

estimation of the average treatment effect. The key identifying assumption is that in the absence of treatment, treated units would have experienced the same trends in average outcomes as the control units i.e. parallel trends assumption. The standard DID estimator rely on the restriction that any unmeasured variables are either time-invariant group attributes or time-varying factors that are unit invariant. Together, these two restrictions supplemented with variation in timing of the treatment, produce a spurious effect and lead to underidentification issues (Callaway and Sant'Anna, 2019; Imai and Kim, 2019a). In this paper, we follow the solution to this issue proposed by (Athey and Imbens, 2018; Borusyak and Jaravel, 2018) and we restrict the pre-trends in “semi-dynamic” settings while keeping the unit and time fixed effects for complete sample (control and treated units). But to do so, the researcher has to justify the absence of anticipation factor, so that the event has a randomly assigned adoption date, and consequently, neither the pre-trends nor expectations cannot influence the outcome. There are a few points that could provide a sound rationale for it. Due to the complexity of stress testing exercise it is very difficult to judge affront the magnitude of effect, even though the date is announced, the scenarios and methodology are known. The mixed market reaction of investors on the date of announcement of the stress test and the date of published results documented by (Candelon and Sy, 2015; Carboni et al., 2017) can also provide supportive evidence for it. Sometimes the inconsistencies and uncertainties on the supervisory side can contribute too (Agarwal et al., 2014). In reality, the outcome cannot be adapted in anticipation of the event instantaneously, since the impact of policy allows to be evaluated mostly ex-post, only after performing the complex process of data collection, modelling, calculations and analysis. On the singular institutional level, there is a certain degree of uncertainty in the outcome, for example, because the regulatory scenarios are different from internal models and they are usually more stringent (Bassett and Berrospide, 2018). Secondly, the structural changes in portfolio and business models require longer horizon for appropriate adjustments, even though regulatory stress test scenarios become more predictive with a time passed-by (Glasserman and Tangirala, 2016).

Practically, we incorporate it in our specification by censoring the combined sample (control and treated group) for a period covering three waves of events i.e. regulatory stress test rounds in 2011, 2014 and 2016 from announcement in 2011 to last available results of published stress tests until 2018 (timeline of events reported in Section 3). In this case, the units that never receive treatment (i.e. never participated in stress-tested rounds) and the units that receive treatment in the future serve as a control group for the cohort of units that have already received treatment. The units that never received the treatment, being a part of the control group are used for estimation of the time effects independently of the causal effect of treatment. In this approach, we avoid the problem with extrapolation and negative weights due to the variation in treatment timing of the standard two-way two-period DID estimator, and hence it enables us to analyse the average treatment effect on treated more robust (Borusyak and Jaravel, 2018).

We adopt the potential outcome framework of Rubin-Newman (Rubin, 2005) for binary treatment in cross-sectional studies to the set-up of the event studies following methodologies (Abraham and Sun, 2018; Athey and Imbens, 2018; Borusyak and Jaravel, 2018; Callaway and Sant'Anna, 2019). Let us consider a panel of

$i = 1, \dots, N$ units in which the outcome Y_{it} is observed for the $t = 1, \dots, T$ periods (calendar time). In our settings, every unit receives treatment at some period E_i within the sample and stays treated forever. The indicator of treatment effect W_i is taking a binary form of a value 1 for the treated unit and 0 for the unit that was not treated. Let K indicate a number of periods before the event E_i , then it can be defined as $K_i = t - E_i$. This indicates the time of periods relative to the event E_i . Then, the indicator variable of being treated can be formulated as $W_{it} \equiv W(E_i, t) = 1\{t \geq E_i\} = 1\{K_{it} \geq 0\}$. For each unit, we observe a treatment path that is a non-decreasing sequence of zeros and then ones, starting from event or adoption date (Abraham and Sun, 2018; Athey and Imbens, 2018). The group of treated units during the same period we refer to as a cohort e . If we denote the baseline outcome with treatment Y_{it}^e and never treated as potential outcome Y_{it}^∞ , then a treatment effect for a given event period and cohort of units can be defined as the difference between the baseline outcome and the potential outcome: $Y_{it}^e - Y_{it}^\infty$. Thus, considering the timing of the events, the observed outcome for each unit is (Abraham and Sun, 2018):

$$Y_{it}^{obs} = Y_{it}^\infty + \sum_{1 \leq e \leq T} (Y_{it}^e - Y_{it}^\infty) \cdot 1\{E_i = e\}, \quad (4)$$

We employ the standard linear regression model for the panel data and saturate the model with unit and time fixed effects, interactions with treatment indicator and considering the covariates or confounders X_i . The specification is defined as in equation (5):

$$Y_{it}^{obs} = \alpha_i + \delta_t + \tau \cdot W_{it} + \gamma' X_{it} + \varepsilon_{it}, \quad (5)$$

and by considering the interactions with changes in capital or buffer measure (from Method 1) as below:

$$Y_{it}^{obs} = \alpha_i + \delta_t + \tau \cdot W_{it} + \beta(C \cdot W)_{it} + \gamma' X_{it} + \varepsilon_{it}, \quad (6)$$

where the observed outcome Y denotes a change in risk profile proxied by risk and performance metrics (ratios of RWATA, NPL and changes in their components RWA, Loan) and X_{it} is a set of time-varying covariates. The covariates X_i are the observable characteristics of the treated and control bank units, identical to previous specifications in Method 1, namely: size of the bank's assets, a level of efficiency, funding and liquidity structure, capitalization. The single effect of supervisory stress test isolated from other capital policies is captured in the equation (6) by element of the interaction between the treatment indicator W_{it} and the explanatory variable $C_{it} = \Delta CET1R_{it}$ or as alternative with buffer measure $(\Delta CET1R * BUF)_{it}$. Finally, α_i is a unit of fixed effects and δ_t is a set of year fixed effects, included to control for variation over time. We assume that the unobserved component satisfies the distributional qualities $\varepsilon_{it} \sim iid(0, \sigma^2)$.

If we denote $\hat{\alpha}^{ols}$, $\hat{\tau}^{ols}$, $\hat{\beta}^{ols}$, $\hat{\gamma}^{ols}$ then the proposed specification in Eq. (5) without interaction with capital changes provides the estimates of OLS (Athey and Imbens, 2018; Imbens and Rubin, 2015) as follows:

$$(\hat{\tau}^{ols}, \hat{\alpha}^{ols}, \hat{\delta}^{ols}, \hat{\gamma}^{ols}) = \arg \min_{\tau, \alpha, \delta, \gamma} \sum_{t=1}^T \sum_{i=1}^N \{Y_{it} - \alpha_i - \delta_t - \tau \cdot W_{it} - \gamma' X_{it}\}^2 \quad (7)$$

and with the interaction to the capital changes as in Eq.(6), the estimates are:

$$(\hat{\beta}^{ols}, \hat{\tau}^{ols}, \hat{\alpha}^{ols}, \hat{\delta}^{ols}, \hat{\gamma}^{ols}) = \arg \min_{\beta, \alpha, \delta, \tau, \gamma} \sum_{t=1}^T \sum_{i=1}^N \{Y_{it} - \alpha_i - \delta_t - \tau \cdot W_{it} - \beta(C_{it} \cdot W_{it}) - \gamma' X_{it}\}^2 \quad (8)$$

The final results of $\hat{\tau}^{ols}$ and $\hat{\beta}^{ols}$ in equations (7) and (8) respectively are consistent with ATET and signify a potential causal effect from the enhanced regulatory scrutiny of stress test. The least-square estimates $\hat{\tau}^{ols}$ and $\hat{\beta}^{ols}$ are commonly interpreted as the weighted average of ATETs across all cohorts (de Chaisemartin and D'Haultfœuille, 2018; Goodman-Bacon, 2018; Imai and Kim, 2019b). The estimated τ indicates whether the changes in risk behaviour are associated with the enhanced scrutiny of stress testing. A finding that β is statistically different from zero suggests that the bank's responses in question are associated with additional capital requirements caused by the regulatory stress test in the sample. If none of the mentioned coefficients is statistically significant, except of γ this indicates that the changes in risks are associated with endogenous bank characteristics and there is no evidence linked to participation in regulatory stress tests.

We test the specification on the appropriateness of the linear regression with two-way fixed effects in comparison to DID estimator by a specification test for heteroskedasticity (White, 1980) as suggested in the study of (Imai and Kim, 2019a, 2019b). Table 5 reports the results of the model and specification tests.

By accounting for the heterogeneity of treatment effect in time-dynamics we find that the portfolio risk measured by risk density (RWATA) declines for the banks subject to regulatory scrutiny of stress test, as reported in column (5) and (9). That is primarily attributable to the decrease in risk-weighted assets, reported in columns (3), (7) and (11). The findings are robust and the estimated coefficients are significant with confidence level 5% and 1%, and steadily increasing the normal and adjusted R- values with inclusion of interaction terms in the models. It is valid for the event treatment variable in binary form, in column (3) and even more significant by interaction with the CET1 ratio and instrumental variable buffer, in columns (5) and (7), (9) and (11) respectively.

Our results are in line with (Acharya et al., 2014; Plosser and Santos, 2018), who argue that the strong reliance on the stress tests metrics on the risk-weights leads to the incentives of risk-shifting to lower risk-weighted portfolio e.g. sovereign exposure and thus amplifying the sovereign risk or leading to underreporting the risk to regulators. By contrast to Bassett and Berrospide (2018) and Pierret and Steri (2019), we do not observe the negative effect on the lending activities, columns (4), (8) and (12), the coefficients are not significant. Though, it can be attributable to the presence of heteroskedasticity problems in this specification as the results of the test (White, 1980) suggest. The outcome coefficients for changes in portfolio quality are not statistically significant in all specifications, columns (2), (6) and (10). So we conclude that the regulatory stress tests did not have any impact on the write-off strategies or ex-ante changes in portfolio quality.

Table 5. Results of regression model with heterogeneous treatment effect in time-dynamic settings

| VARIABLES | Dependent Variables Annual Change (pp and %) | | | | | | | | | | | |
|--------------------------------------|--|---------|----------|----------|-----------|---------|-----------|-----------|------------------|------------------|------------------|------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| | RWATA | NPL | RWA | LOAN | RWATA | NPL | RWA | LOAN | RWATA | NPL | RWA | LOAN |
| Δ CET1R x W x BUF | | | | | | | | | -0.057*** | 0.009 | -0.282*** | -0.060 |
| | | | | | | | | | (0.017) | (0.008) | (0.087) | (0.038) |
| Δ CET1R x W | | | | | -0.005*** | 0.001 | -0.014*** | -0.004 | | | | |
| | | | | | (0.002) | (0.001) | (0.005) | (0.003) | | | | |
| W | -0.011 | 0.005 | -0.052** | 0.001 | -0.011 | 0.004 | -0.054* | 0.006 | -0.019 | 0.002 | -0.059** | -0.002 |
| | (0.012) | (0.005) | (0.023) | (0.021) | (0.013) | (0.005) | (0.028) | (0.023) | (0.016) | (0.004) | (0.027) | (0.022) |
| Constant | 0.598*** | -0.007 | -0.069 | -1.409** | 0.618*** | -0.003 | 0.027 | -1.566*** | 0.508*** | 0.036 | -0.054 | -1.442** |
| | (0.175) | (0.123) | (0.552) | (0.562) | (0.180) | (0.122) | (0.457) | (0.534) | (0.175) | (0.115) | (0.431) | (0.574) |
| Unit FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes ¹ | Yes ¹ | Yes ¹ | Yes ¹ |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2,039 | 1,808 | 2,035 | 2,056 | 2,039 | 1,808 | 2,035 | 2,053 | 2,039 | 1,805 | 2,035 | 2,056 |
| R ² | 0.260 | 0.267 | 0.389 | 0.344 | 0.231 | 0.267 | 0.361 | 0.363 | 0.239 | 0.330 | 0.364 | 0.339 |
| Adjusted R ² | 0.0816 | 0.0834 | 0.240 | 0.187 | 0.0461 | 0.0838 | 0.205 | 0.210 | 0.0556 | 0.161 | 0.208 | 0.181 |
| F test | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| White's test for Heteroscedasticity: | | | | | | | | | | | | |
| chi2 | 385.55 | 859.45 | 536.98 | 89.50 | 366.31 | 427.05 | 536.98 | 83.56 | 370.10 | 634.93 | 584.98 | 58.37 |
| Prob > chi2 | 0.000 | 0.000 | 0.000 | 0.8069 | 0.000 | 0.000 | 0.000 | 0.990 | 0.000 | 0.000 | 0.000 | 0.9998 |

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Note: Time effects are adjusted to the dates of the instrumental variable, i.e. we exclude the dummy of the year 2013 from calculation.

4.4 Additional analysis with the application of simultaneous equations under the “selection on unobservables” (Method 3)

The most common limitation of previous specification (Method 2) is that we rely on several assumptions that in reality are difficult to hold, and correspondingly the specification results in a biased estimate due to the unobserved heterogeneity. The analysed units are financial institutions that are complex by nature of the business and they operate in time-dynamic environment with perplexed regulatory framework, where many policies and interventions intermix, and therefore have multiple direct and indirect effects with unknown temporal lags. For example, referring to the sampling methodology of regulatory stress tests rounds, there are formal criteria for selection into the sample existing that allows us “selection on observables”. Nevertheless, there are many factors that can affect e.g. the evolving nature of methodologies or there is always an option for the banking institutions to be included into the regulatory stress test rounds on the basis of systemic importance and on the discretion of supervisory authorities. Because of all these unobservable factors, it is logical to investigate further under less restrictive assumptions, and using not only observable criteria but consider the “selection on unobservables” that potentially can improve the validity of our specification.

The instrumental variable approach with the engagement of two simultaneous equations (two-stage least-square) can potentially provide a better estimation if the proper instrument variable is available and qualifies

for it. The application of instrumental variable approach requires the availability of some variable (z), we refer to as instrumental variable (IV) or instrument, that satisfies the following properties (Angrist and Krueger, 2001; Angrist and Pischke, 2009; Wooldridge, 2012):

- (i) instrument z has to directly correlate with the treatment w ;
- (ii) instrument z has no direct effect on outcome y only through the treatment indicator w ;
- (iii) instrument z is independent of unmeasured confounders u given the measured covariates x .

The qualifying of these properties commonly refer to “exclusion restriction” criteria (Imbens, 2014). The IV approach allows us to identify the causal effect of w on y by estimating the portion of variation in the outcome y associated with the treatment w that is attributable to the exogenous instrument variables z . Since, the regulatory stress tests, in essence, represent the hypothetical capital that is available in situation of the economic adverse conditions, it is rational to link the instrument variable to the changes in actual capital, similarly as we did in Methods 1 and 2. Therefore, we define the IV for a unit i as

$$z_i = (\Delta CET1R * BUF)_i,$$

where $\Delta CET1R$ denotes an annual change in CET1 ratio, and BUF is a measure variable (see Section 3.1). The measure BUF that is indicating the gap or surplus of stressed capital serves as an indicator of the strength of regulatory scrutiny effect on the banks. Referring to the logic behind calculations of the IV z (technical description provided in Section 3) it is reasonable to assume, first of all, that it is associated directly with treatment effect w , and second, it is exogenous by nature. Noting the fact that the assigned scenarios are set on the discretion of EBA, and assuming that they are not influenced anyhow by the banks itself, we can consider them as exogenously imposed on the banking institutions. We perform also a set of standard tests to confirm the exogenous qualities and hence the suitability for instrumental variable.

The second assumption asserts that the instrument z has no direct impact on outcome y that is the change in risk behaviour, only through treatment indicator w . By set-up, the IV captures the size of hypothetical capital available according to the results of regulatory stress test by considering the adverse economic scenario. It can be viewed as an indicator of the size of impact from regulatory scrutiny. If the value of z is very small, its effect (through the treatment indicator) on outcome y is negligible, but if the value of z is large enough it can have stronger effect and correspondingly larger implications (Georgescu et al., 2017; Goldstein and Sapra, 2014; Goncharenko et al., 2018).

In a standard way, the econometric approach to estimation of the causal effects with instrumental variables implies the structural form of equations in form of Two-Stage-Least-Squares (2SLS) and in case of the binary treatment indicator Probit OLS or Probit 2SLS can provide more robust estimates. In this analysis, we employ the regression models with idiosyncratic or heterogeneous average treatment effects within the potential outcome framework of Rubin-Newman (Rubin, 2005). We adopt the potential outcome framework in line with proposed methodologies (Cerulli et al., 2014; Wooldridge, 2010) and with technical implementation of STATA

“ivtreatreg” routine developed by (Cerulli, 2014). The detailed explanation about the concept of potential outcome and underlining models is provided in the Appendix.

Technically, we solve the system of structural equations by running the two regression models with observable and unobservable heterogeneous treatment effects: direct-2SLS (IV regression estimated by direct two-stage least squares), Probit-OLS (IV two-step regression estimated by Probit and OLS) and Probit-2SLS (IV regression estimated by probit and two-stage least squares). The procedure steps in the calculation of the structural equations can be summarized as:

- (i) estimate the \hat{w} by regressing on IV z and set of covariates x (OLS) or by applying the probit and assessing the predicted probability of \hat{w} (Probit-OLS, Probit-2SLS);
- (ii) estimate the treatment effect τ by regressing y on \hat{w} and covariates x to account for observable heterogeneity.

The observable characteristics x_i are the covariates, identical to previous specifications in Method 1 and 2, namely: size of the bank’s assets, a level of efficiency, funding and liquidity structure, total capitalization.

Our instrumental variable and specifications were tested on the assumptions associated with a valid instrument as proposed in studies (Angrist and Pischke, 2009; Wooldridge, 2012, 2010). First, we used a first-stage F-test to determine if there was evidence of weak instrument problems. Using the F-test criteria for the 2SLS specifications with various outcome variables, we were able to reject the null hypothesis of a weak instrument in all cases. We also employed a test on the over-identifying restrictions that is the specification test of Sargan-Hansen with J-statistics. In all four instances, the test confirms that the equations are exactly identified and we do not reject the joint null hypothesis that the instrumental variable is a valid instrument. Finally, we conducted a test to determine whether the treatment variable is endogenous (Durbin-Wu-Hausman’s chi-sq test and Wu-Hausman’s F-test)⁴. In three of the four models, we were able to reject the null hypothesis that the treatment variable was exogenous at the 10% significance level or lower, and in most of the remaining models, we had few cases only with the outcome variable changes in RWA (that is the denominator of the CET1R ratio). We run also Heckman’s correction model, with the procedure name “heckit” (Wooldridge, 2010) as a robustness check for our 2SLS specifications and a test on bias from non-random sample selection and omitted variables. Table 6 reports the summary of the results of ATE from three structural models with separately estimated t-test, Heckman’s model, while the detailed results of regression models with instrumented variables, and coefficients of ATE, ATET and ATENT are presented in Appendix Table D.

Table 6. Summary of estimation of the ATE for the four models

Panel A

Dependent Variable: $\Delta RWATA$ (in pp)

| Variable | ttest | probit_ols | probit_2sls | direct_2sls | heckit |
|----------|-------|------------|-------------|-------------|--------|
|----------|-------|------------|-------------|-------------|--------|

⁴ Since “ivtreatreg” STATA routine (Cerulli, 2014) does not provide post-estimation test option, we employed “ivreg2” command to re-estimate and run post-estimation tests. The results of the tests are summarized above and in details available upon request.

| | | | | | |
|----|---------|---------|----------|----------|----------|
| w_ | -0.029* | -0.076* | -0.040** | -0.194** | -0.066** |
|----|---------|---------|----------|----------|----------|

legend: * <0.05; ** p<0.01; *** p<0.001

Panel B

| Dependent Variable: Δ NPL (in pp) | | | | | |
|--|-------|------------|-------------|-------------|--------|
| Variable | ttest | probit_ols | probit_2sls | direct_2sls | heckit |
| w_ | 0.001 | 0.006 | 0.003 | 0.000 | -0.005 |

legend: * p<0.05; ** p<0.01; *** p<0.001

Panel C

| Dependent Variable: Δ RWA (in %) | | | | | |
|---|----------|------------|-------------|-------------|-----------|
| Variable | ttest | probit_ols | probit_2sls | direct_2sls | heckit |
| w_ | -0.098** | -0.375*** | -0.203*** | -0.905*** | -0.482*** |

legend: * p<0.05; ** p<0.01; *** p<0.001

Panel D

| Dependent Variable: Δ LOAN (in %) | | | | | |
|--|-----------|------------|-------------|-------------|--------|
| Variable | ttest | probit_ols | probit_2sls | direct_2sls | heckit |
| w_ | -0.045*** | -0.162 | -0.078 | -0.156 | -0.108 |

Legend: * p<0.05; ** p<0.01; *** p<0.001

Overall, we observe that the instrumental variable models successfully passed the majority of tests and were particularly better for the categories of the outcome variable of risk metrics: RWATA, LOAN and NPL. By comparing the results of structural models with simple t-test on difference in mean (reported in Table 6), the conclusion can be drawn that regulatory stress has an impact on the changes in portfolio risk measured by changes in risk density (Panel A), while seemingly it does not impact the portfolio quality (Panel B). Assuming that the results for the outcome variable changes in RWA are not strongly distorted by the endogeneity issues, they indicate the major contribution to the changes in risk density. In line with previous observations, the mixed results are reported for indicator changes in loan volumes (Panel D). In summary, all results of structural models with instrumented variables in Method 3 reiterate the findings from previous specifications in Methods 1 and 2.

5 Summary of Results and Regulatory Implications

In summary of the study, we report the evidence of the substantial impact of regulatory stress testing on the adjustment strategies of the banking institutions. In response to the enhanced scrutiny and additional capital requirements of the EU-wide stress tests in 2011, 2014 and 2016, we document a decrease in riskiness of portfolios mostly attributable to the decline in risk-weighted assets. This is arguably indicating the decrease of

realized risk, as we can't find any impact on the changes in the quality of the portfolio. The coefficients of alternative risk metrics NPL are not significant in all specifications: Method 1, 2 and 3. Similarly, Acharya et al. (2014) find that the regulatory risk-weights of stress tests have no link with the realized risk of banks during a crisis period. In general, we observe a mixed effect on the lending activities. Probably it is not distinguishable from other ongoing policies or due to the endogenous bank-specific factors. At the same time, we observe that the changes in CET1 ratio are clearly associated with decline in loan volume growth in our sample, similarly for both treated and control groups, as reported in Table 3, columns (7) and (8).

The results of other specifications with treatment effect (Method 2) and instrumental variable (Method 3) do not clearly prove the constraining effect, specifically stemming from capital requirements of regulatory stress testing. On the other hand, we find that the stress-tested banks do not engage themselves in moral hazard behaviour i.e. increased risk in portfolio or excessive loan growth, hence they achieve the goal of promoting prudent lending practices.

The analysis of the heterogeneity of treatment effect in time-dynamic settings (Method 2 and 3) points to the lasting adjustments in balance sheet and portfolio structures in response to the regulatory stress tests. Over the observation period of 2011 to 2018, we find a strong effect that has been distributed evenly over the three waves of regulatory stress tests rounds. Similar to results of (Bräuning and Fillat, 2019; Plosser and Santos, 2018), we conclude that the business models and portfolio structure have been constantly adapting toward the less risky portfolios and, probably with less sensitive exposure to economic shock. Therefore, by relying on the capital ratios and risk-weights in assessment of the stress test outcome for a singular bank unit, there is a concern on creating incentives toward portfolio shifting to the lower risk and less capital intensive assets, as risk-weight assets are the denominator of the capital ratios. Potentially it could create prerequisites for systemic risks in the concentration of certain type of assets and lead to the misguidance on the asset-risk return allocation, irrespective of the supplementary leverage metrics (Acharya et al., 2014).

The fact that the “bottom-up” approach let the riskiness of assets be determined on the basis of internal risk models, raises the importance of the elaborated risk model landscape. Thereby, it should be accompanied by strong risk governance within organizations (Stein and Wiedemann, 2018) in order to avoid the situation of “institutionalizing” model risk (Kupiec, 2019; Witzany, 2017b) and materially underestimate the vulnerability of banks to adverse circumstances (European Central Bank, 2019).

The indicated long-lasting effect on the adjustment strategies might clearly challenge the major simplification assumption i.e. the static balance sheet assumption, in the stress testing methodology that does not consider the dynamic adjustments in the balance sheet and portfolios. Similarly, the studies of alternative assumptions e.g. (Busch et al., 2017) on the example of stress-tested banks in Germany, indicate the presence of temporal dynamics in banks responses that differentiates strongly between the large and smaller banks.

Drawing on our “ex-post” analysis should enable the institutions and regulators to define and calibrate new rules and fine-tune methodologies by including the bank reactions and portfolio dynamics. Practically, this

study contributes to the development of more realistic scenarios and methodologies of microprudential stress testing, thus leading to improvements in the evaluation of financial system resilience to economic shocks.

6 Conclusions

In this article, we investigated the bank's response to the enhanced regulatory scrutiny and additional capital requirements from regulatory stress testing. Using the econometric approach of event study and causal inference on the dataset that includes the banks subject to EU-wide stress testing exercises in 2011, 2014 and 2016, we find the evidence of significant and lasting impact of regulatory stress tests on the balance sheet and portfolio adjustments.

Our findings suggest that banking institutions decreased the riskiness of portfolios in response to the enhanced scrutiny and additional capital requirements of the regulatory stress tests. That is observed in the decline of the risk density in portfolio, and mostly attributable to the steady decrease in the risk-weighted assets. Seemingly it does not affect the realized risk that is measured by the changes in proportion of non-performing exposure in portfolios. We, therefore, argue that the current methodological set-up of regulatory stress testing incentivizes banks to alter a mix of assets in their balance sheets towards less capital-intensive areas, and thus create concerns on the systemic concentration of risk in certain type of assets.

Mixed results in specifications do not allow us evidently to judge on the presence of constraining factor on lending activities. Conversely, we find that the stress-tested banks do not engage in moral hazard behaviour i.e. increased risk in portfolio or excessive loan growth, thus the regulatory stress tests fulfil the objective of promoting prudent risk management practices.

In summary, our study should raise the attention of the institutions and regulators to importance of the singular bank reactions and dynamics in portfolio adjustments for the calibration and development of new rules and fine-tuning the methodologies of stress tests. This article contributes to the development of more realistic scenarios and methodologies of microprudential stress testing, thus leading to the improvements in the evaluation of financial system resilience to economic shocks.

References

- Abraham, S., Sun, L., 2018a. Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects (No. 1804.05785), Papers. arXiv.org.
- Abraham, S., Sun, L., 2018b. Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects. arXiv:1804.05785 [econ].
- Acharya, V., Engle, R., Pierret, D., 2014. Testing macroprudential stress tests: The risk of regulatory risk weights. *Journal of Monetary Economics*, Carnegie-Rochester-NYU Conference Series on Public Policy “A Century of Money, Banking, and Financial Instability” held at the Tepper School of Business, Carnegie Mellon University on November 15-16, 2013 65, 36–53. <https://doi.org/10.1016/j.jmoneco.2014.04.014>
- Acharya, V.V., Berger, A.N., Roman, R.A., 2018a. Lending implications of U.S. bank stress tests: Costs or benefits? *Journal of Financial Intermediation*, Assessing Banking Regulation During the Obama Era 34, 58–90. <https://doi.org/10.1016/j.jfi.2018.01.004>
- Acharya, V.V., Berger, A.N., Roman, R.A., 2018b. Lending implications of U.S. bank stress tests: Costs or benefits? *Journal of Financial Intermediation* 34, 58–90.
- Acharya, V.V., Berger, A.N., Roman, R.A., 2017. Lending Implications of U.S. Bank Stress Tests: Costs or Benefits? (SSRN Scholarly Paper No. ID 2972919). Social Science Research Network, Rochester, NY.
- Acharya, V.V., Mehran, H., Thakor, A.V., 2015. Caught between Scylla and Charybdis? Regulating Bank Leverage When There Is Rent Seeking and Risk Shifting. *Review of Corporate Finance Studies* cfv006. <https://doi.org/10.1093/rcfs/cfv006>
- Agarwal, S., Lucca, D.O., Seru, A., Trebbi, F., 2014. Inconsistent Regulators: Evidence from Banking. *The Quarterly Journal of Economics* 129, 889–938.
- Aggarwal, R., Jacques, K.T., 2004. The impact of FDICIA and prompt corrective action on bank capital and risk: Estimates using a simultaneous equations model. *Journal of Banking & Finance* 25, 1139–1160. [https://doi.org/10.1016/S0378-4266\(00\)00125-4](https://doi.org/10.1016/S0378-4266(00)00125-4)
- Ahnert, L., Vogt, P., Vonhoff, V., Weigert, F., 2018. The Impact of Regulatory Stress Testing on Bank’s Equity and CDS Performance (SSRN Scholarly Paper No. ID 3179540). Social Science Research Network, Rochester, NY.
- Andersen, H., Gerdrup, K.R., Johansen, R.M., Krogh, T., 2019. A Macroprudential Stress Testing Framework (Working paper). Norges Bank.
- Angrist, J.D., Krueger, A.B., 2001. Instrumental Variables and the Search for Identification: From Supply and Demand to Natural Experiments. *Journal of Economic Perspectives* 15, 69–85. <https://doi.org/10.1257/jep.15.4.69>
- Angrist, J.D., Pischke, J.-S., 2009. *Mostly Harmless Econometrics: An Empiricist’s Companion*. Princeton University Press.
- Athey, S., Imbens, G.W., 2018. Design-based Analysis in Difference-In-Differences Settings with Staggered Adoption (Working Paper No. 24963). National Bureau of Economic Research. <https://doi.org/10.3386/w24963>
- Bassett, W.F., Berrospide, J.M., 2018. The Impact of Post Stress Tests Capital on Bank Lending (No. 2018–087), Finance and Economics Discussion Series. Board of Governors of the Federal Reserve System (US).
- Berger, A.N., Bouwman, C.H.S., 2012. How Does Capital Affect Bank Performance During Financial Crises? (SSRN Scholarly Paper No. ID 1739089). Social Science Research Network, Rochester, NY.
- Besanko, D., Kanatas, G., 1996. The Regulation of Bank Capital: Do Capital Standards Promote Bank Safety? *Journal of Financial Intermediation* 5, 160–183. <https://doi.org/10.1006/jfin.1996.0009>
- Blossfeld, H.-P., Rohwer, G., Schneider, T., 2019. *Event history analysis with Stata*, 2nd ed. Routledge.
- Borusyak, K., Jaravel, X., 2018. Revisiting Event Study Designs , with an Application to the Estimation of the Marginal Propensity to Consume *.
- Bräuning, F., Fillat, J.L., 2019. Stress Testing Effects on Portfolio Similarities Among Large Us Banks (SSRN Scholarly Paper No. ID 3416874). Social Science Research Network, Rochester, NY.

- Budnik, K.B., Balatti, M., Covi, G., Dimitrov, I., Groß, J., Hansen, I., Kleemann, M., Reichenbachas, T., Sanna, F., Sarychev, A., Siņenko, N., Volk, M., Cera, K., di Iasio, G., Giuzio, M., Mirza, H., Moccerò, D., Nicoletti, G., Pancaro, C., Palligkinis, S., 2019. Macroprudential Stress Test of the Euro Area Banking System (SSRN Scholarly Paper No. ID 3414174). Social Science Research Network, Rochester, NY.
- Busch, R., Drescher, C., Memmel, C., 2017. Bank stress testing under different balance sheet assumptions (No. 07/2017), Discussion Papers. Deutsche Bundesbank.
- Calem, P.S., Correa, R., Lee, S.J., 2017. Prudential Policies and Their Impact on Credit in the United States (SSRN Scholarly Paper No. ID 2967129). Social Science Research Network, Rochester, NY.
- Callaway, B., Sant'Anna, P.H.C., 2019. Difference-in-Differences with Multiple Time Periods (SSRN Scholarly Paper No. ID 3148250). Social Science Research Network, Rochester, NY.
- Camara, B., Lepetit, L., Tarazi, A., 2013. Ex Ante Capital Position, Changes in the Different Components of Regulatory Capital and Bank Risk (No. 7), *Débats économiques et financiers*. Banque de France.
- Campbell, T.S., Kracaw, W.A., 1980. Information Production, Market Signalling, and the Theory of Financial Intermediation. *The Journal of Finance* 35, 863–882. <https://doi.org/10.2307/2327206>
- Candelon, B., Sy, A.N.R., 2015. How Did Markets React to Stress Tests? International Monetary Fund.
- Carboni, M., Fiordelisi, F., Ricci, O., Lopes, F.S.S., 2017. Surprised or not surprised? The investors' reaction to the comprehensive assessment preceding the launch of the banking union. *Journal of Banking & Finance* 74, 122–132. <https://doi.org/10.1016/j.jbankfin.2016.11.004>
- Card, D., Krueger, A.B., 2000. Minimum Wages and Employment: A Case Study of the Fast-Food Industry in New Jersey and Pennsylvania: Reply. *American Economic Review* 90, 1397–1420. <https://doi.org/10.1257/aer.90.5.1397>
- Cerulli, G., 2015. *Econometric Evaluation of Socio-Economic Programs: Theory and Applications*, Advanced Studies in Theoretical and Applied Econometrics. Springer-Verlag, Berlin Heidelberg.
- Cerulli, G., 2014. `ivtreatreg`: A command for fitting binary treatment models with heterogeneous response to treatment and unobservable selection. *Stata Journal* 14, 453–480.
- Cerulli, G., Gabriele, R., Tundis, E., 2014. Identification and estimation of treatment effects in the presence of neighbourhood interactions. Louvain-la-Neuve: European Regional Science Association (ERSA).
- Cohen, B., Scatigna, M., 2016. Banks and capital requirements: Channels of adjustment. *Journal of Banking & Finance* 69, S56–S69.
- Cortés, K., Demyanyk, Y., Li, L., Loutskina, E., Strahan, P.E., 2018. Stress Tests and Small Business Lending (Working Paper No. 24365). National Bureau of Economic Research. <https://doi.org/10.3386/w24365>
- de Chaisemartin, C., D'Haultfoeuille, X., 2018. Two-way fixed effects estimators with heterogeneous treatment effects. [arXiv:1803.08807 \[econ\]](https://arxiv.org/abs/1803.08807).
- Diamond, D.W., 1984. Financial Intermediation and Delegated Monitoring. *The Review of Economic Studies* 51, 393–414. <https://doi.org/10.2307/2297430>
- Dvouletý, O., Blažková, I., 2018. Assessing the microeconomic effects of public subsidies on the performance of firms in the Czech food processing industry: A counterfactual impact evaluation. *Agribusiness* 0. <https://doi.org/10.1002/agr.21582>
- Dvouletý, O., Čadil, J., Mirošník, K., 2019. Do Firms Supported by Credit Guarantee Schemes Report Better Financial Results 2 Years After the End of Intervention? *The B.E. Journal of Economic Analysis & Policy* 19. <https://doi.org/10.1515/bejeap-2018-0057>
- Eber, M., Minoiu, C., 2016. How Do Banks Adjust to Stricter Supervision? (SSRN Scholarly Paper No. ID 2662502). Social Science Research Network, Rochester, NY.
- European Banking Authority, 2016. European Banking Authority [WWW Document]. EBA launches 2016 EU wide stress test exercise. URL <https://eba.europa.eu/-/eba-launches-2016-eu-wide-stress-test-exercise> (accessed 9.15.19).
- European Central Bank, 2019. The evolution of stress-testing in Europe [WWW Document]. The evolution of stress-testing in Europe. URL https://www.ecb.europa.eu/press/key/date/2019/html/ecb.sp190904_2~4c8236275b.en.html (accessed 9.23.19).

- Flannery, M., Hirtle, B., Kovner, A., 2017. Evaluating the information in the federal reserve stress tests. *Journal of Financial Intermediation* 29, 1–18. <https://doi.org/10.1016/j.jfi.2016.08.001>
- Flannery, M.J., 2013. Measuring Equity Capital for Stress -- Testing Large Financial Institutions (SSRN Scholarly Paper No. ID 2370104). Social Science Research Network, Rochester, NY.
- Furlong, F.T., Keeley, M.C., 1991. Capital regulation and bank risk-taking: a note (reprinted from *Journal of Banking and Finance*). *Economic Review* 34–39.
- Georgescu, O.M., Gross, M., Kapp, D., Kok, C., 2017a. Do Stress Tests Matter? Evidence from the 2014 and 2016 Stress Tests (SSRN Scholarly Paper No. ID 2968952). Social Science Research Network, Rochester, NY.
- Georgescu, O.M., Gross, M., Kapp, D., Kok, C., 2017b. Do Stress Tests Matter? Evidence from the 2014 and 2016 Stress Tests (SSRN Scholarly Paper No. ID 2968952). Social Science Research Network, Rochester, NY.
- Glasserman, P., Tangirala, G., 2016. Are the Federal Reserve's Stress Test Results Predictable? *The Journal of Alternative Investments* 18, 82. <https://doi.org/10.3905/jai.2016.18.4.082>
- Goldstein, I., Sapra, H., 2014. Should Banks' Stress Test Results be Disclosed? An Analysis of the Costs and Benefits. *FIN* 8, 1–54. <https://doi.org/10.1561/05000000038>
- Goncharenko, R., Hledik, J., Pinto, R., 2018. The dark side of stress tests: Negative effects of information disclosure. *Journal of Financial Stability* 37, 49–59. <https://doi.org/10.1016/j.jfs.2018.05.003>
- Goncharenko, R., Rauf, A., 2019. Loan Loss Provisioning Requirements in a Dynamic Model of Banking (SSRN Scholarly Paper No. ID 3247631). Social Science Research Network, Rochester, NY.
- Goodman-Bacon, A., 2018. Difference-in-Differences with Variation in Treatment Timing (Working Paper No. 25018). National Bureau of Economic Research. <https://doi.org/10.3386/w25018>
- Gropp, R., Mosk, T.C., Ongena, S., Wix, C., 2018. Bank Response to Higher Capital Requirements: Evidence from a Quasi-Natural Experiment (SSRN Scholarly Paper No. ID 2877771). Social Science Research Network, Rochester, NY.
- Imai, K., Kim, I.S., 2019a. On the Use of Two-way Fixed Effects Regression Models for Causal Inference with Panel Data.
- Imai, K., Kim, I.S., 2019b. When Should We Use Unit Fixed Effects Regression Models for Causal Inference with Longitudinal Data? *American Journal of Political Science* 63, 467–490. <https://doi.org/10.1111/ajps.12417>
- Imbens, G.W., 2014. Instrumental Variables: An Econometrician's Perspective. *Statist. Sci.* 29, 323–358. <https://doi.org/10.1214/14-STS480>
- Imbens, G.W., Rubin, D.B., 2015. *Causal Inference for Statistics, Social, and Biomedical Sciences* by Guido W. Imbens, Cambridge Core - Econometrics and Mathematical Methods -.
- Janda, K., Kravtsov, O., 2018. Basel III Leverage and Capital Ratio over the Economic Cycle in the Czech Republic and its Comparison with the CEE Region. *European Financial and Accounting Journal* 2018, 5–24. <https://doi.org/10.18267/j.efaj.216>
- Jeitschko, T.D., Jeung, S.D., 2006. Do Well-Capitalized Banks Take More Risk? Evidence from the Korean Banking System (SSRN Scholarly Paper No. ID 929124). Social Science Research Network, Rochester, NY.
- Kuc, M., Těplý, P., 2015. A Comparison of Financial Performance of Czech Credit Unions and European Cooperative Banks (No. 2015/18), Working Papers IES. Charles University Prague, Faculty of Social Sciences, Institute of Economic Studies.
- Kupiec, P., 2019. Policy Uncertainty, Financial Stability, and Stress Testing (SSRN Scholarly Paper No. ID 3363866). Social Science Research Network, Rochester, NY.
- Leland, H., Pyle, D.H., 1977. Informational Asymmetries, Financial Structure, and Financial Intermediation. *Journal of Finance* 32, 371–87.
- Lindquist, K.-G., 2003. Banks' buffer capital: How important is risk? (No. 2003/11), Working Paper. Norges Bank.

- Matejašák, M., Teplý, P., Černohorský, J., 2009. The impact of regulation of banks in the US and the EU -15 countries.
- Mésonnier, J.-S., Monks, A., 2014. Did the EBA Capital Exercise Cause a Credit Crunch in the Euro Area? (Working paper). Banque de France.
- Petrella, G., Resti, A., 2013. Supervisors as information producers: Do stress tests reduce bank opaqueness? *Journal of Banking & Finance* 37, 5406–5420.
- Pierret, D., Steri, R., 2019. Stressed Banks (SSRN Scholarly Paper No. ID 3066403). Social Science Research Network, Rochester, NY.
- Pierret, D., Steri, R., 2018. Stressed Banks (SSRN Scholarly Paper No. ID 3066403). Social Science Research Network, Rochester, NY.
- Plosser, M.C., Santos, J.A.C., 2018. Banks' Incentives and Inconsistent Risk Models. *Rev Financ Stud* 31, 2080–2112. <https://doi.org/10.1093/rfs/hhy028>
- Roengpitya, R., Tarashev, N., Tsatsaronis, K., Villegas, A., 2017. Bank business models: popularity and performance (No. 682), BIS Working Papers. Bank for International Settlements.
- Rosenbaum, P.R., Rubin, D.B., 1983. The Central Role of the Propensity Score in Observational Studies for Causal Effects. *Biometrika* 70, 41–55. <https://doi.org/10.2307/2335942>
- Rubin, D.B., 2005. Causal Inference Using Potential Outcomes: Design, Modeling, Decisions. *Journal of the American Statistical Association* 100, 322–331. <https://doi.org/10.1198/016214504000001880>
- Schuermann, T., 2013. Stress Testing Banks (SSRN Scholarly Paper No. ID 2041579). Social Science Research Network, Rochester, NY.
- Shrieves, R.E., Dahl, D., 1992. The Relationship between Risk and Capital in Commercial Banks (SSRN Scholarly Paper No. ID 2487420). Social Science Research Network, Rochester, NY.
- Stádník, B., Raudeliūnienė, J., Davidavičienė, V., 2016. Fourier Analysis for Stock Price Forecasting: Assumption and Evidence. *Journal of Business Economics and Management* 17, 365–380. <https://doi.org/10.3846/16111699.2016.1184180>
- Stein, V., Wiedemann, A., 2018. Risk Governance: Basic Rationale and Tentative Findings from the German Banking Sector, in: Idowu, S.O., Sitnikov, C., Simion, D., Bocean, C.G. (Eds.), *Current Issues in Corporate Social Responsibility: An International Consideration, CSR, Sustainability, Ethics & Governance*. Springer International Publishing, Cham, pp. 97–110. https://doi.org/10.1007/978-3-319-70449-4_7
- Sutorova, B., Teplý, P., 2013. The Impact of Basel III on Lending Rates of EU Banks. *Czech Journal of Economics and Finance (Finance a uver)* 63, 226–243.
- Teplý, P., Mejstřík, M., Pečená, M., 2015. *Bankovníctví v teorii a praxi / Banking in Theory and Practice*, e-book. Knihkupectví Karolinum.
- Vozková, K., Teplý, P., 2018. Determinants of Bank Fee Income in the EU Banking Industry - Does Market Concentration Matter? *Prague Economic Papers* 27, 3–20. <https://doi.org/10.18267/j.pep.645>
- White, H., 1980. A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica* 48, 817–838. <https://doi.org/10.2307/1912934>
- Witzany, J., 2017a. A Bayesian Approach to Backtest Overfitting (SSRN Scholarly Paper No. ID 3002503). Social Science Research Network, Rochester, NY.
- Witzany, J., 2017b. Credit Risk Management, in: *Credit Risk Management: Pricing, Measurement, and Modeling*. Springer International Publishing, Cham, pp. 5–18. https://doi.org/10.1007/978-3-319-49800-3_2
- Wooldridge, J., 2012. *Introductory Econometrics: A Modern Approach*, 5th ed. South-Western College Pub.
- Wooldridge, J., 2010. *Econometric Analysis of Cross Section and Panel Data* | The MIT Press.
- Zhang, D., Cai, J., Dickinson, D.G., Kutan, A.M., 2016. Non-performing loans, moral hazard and regulation of the Chinese commercial banking system. *Journal of Banking & Finance* 63, 48–60.

Appendix

Table A. Descriptive statistics, sources and definitions of the variables

This table reports summary statistics and definitions for the variables in our analysis. It contains the number of observations (N), means, standard deviations (Std) and source on all the regression variables.

| Variables | Definitions | N | Mean | Std | Source |
|---|---|------|--------|-------|-----------------------|
| Dependent: Bank Risk & Performance | | | | | |
| <i>ΔRWATA</i> | Annual change of the risk density ratio that is a ratio of the risk-weighted assets (RWA) to the total assets (TA) | 2616 | -0.003 | 0.118 | Orbis BankFocus |
| <i>ΔRWA</i> | The growth rate of the risk-weighted assets (RWA) | 2560 | 0.087 | 0.854 | Orbis BankFocus |
| <i>ΔNPL</i> | Annual change of asset quality ratio, calculated as the proportion of bank nonperforming loans to total loans. Nonperforming loans are loans that are past due for ninety days or more. | 2457 | -0.002 | 0.033 | Orbis BankFocus |
| <i>ALOAN</i> | The growth rate of loan volumes | 2855 | 0.047 | 0.207 | Orbis BankFocus |
| Control Variables | | | | | |
| <i>ACETIR</i> | Common Equity Tier 1 (CET1) capital to risk-weighted assets, annual change | 2426 | 0.725 | 4.090 | Orbis BankFocus |
| <i>TA</i> | Log of the bank gross total assets | 3312 | 9.960 | 1.889 | Orbis BankFocus |
| <i>LAR</i> | Bank liquidity structure, calculated as the ratio of bank cash and short term tradable securities to gross total assets | 2798 | 0.195 | 0.154 | Orbis BankFocus |
| <i>DLR</i> | Funding structure, calculated as the ratio of customer deposits and short term funding to total liabilities | 3303 | 0.741 | 0.228 | Orbis BankFocus |
| <i>COST</i> | Bank efficiency and proxy for a business model, cost-to-income ratio | 3295 | 0.639 | 0.339 | Orbis BankFocus |
| <i>NIM</i> | Bank efficiency indicator. Net interest margin | 3282 | 0.019 | 0.025 | Orbis BankFocus |
| <i>CAR</i> | Bank regulatory capital to risk-weighted assets | 3134 | 0.181 | 0.078 | Orbis BankFocus |
| Instrumental Variable | | | | | |
| <i>BUF</i> | Instrumental variable calculated as a measure of capital gap or surplus based on the published results of EBA stress tests | 571 | 0.046 | 0.059 | EBA reports / website |
| Dummies and Fixed Effects | | | | | |
| <i>W</i> | Event treatment dummy in binary form | 3752 | 0.204 | 0.403 | |
| <i>Bank FE</i> | Dummy variable for each of the banks unit | | | | |
| <i>Time FE</i> | Annual year dummy variables for all time periods | | | | |

Table B. Key facts about the EU-wide regulatory stress test and our sample

This Table reports the key information about the stress test and sample of the banks we used for our study.

| | 2010 | 2011 | 2014 | 2016 | 2018 |
|--|------------|------------|--------------|------------|------------|
| Announcement Date | 18/06/2010 | 13/01/2011 | 31/01/2014 | 05/11/2015 | 31/01/2018 |
| Release Date | 26/07/2010 | 18/07/2011 | 27/10/2014 | 01/08/2016 | 02/11/2018 |
| Competent authority | CEBS | CEBS | EBA | EBA | EBA |
| # banks tested (of which in our sample) | 91 - | 90 (70) | 123 (110) | 51 (51) | 49 - |

| | | | | | |
|---|---|--|--|--|---|
| # banks failed (of which in sample) | 7 - | 8 (4) | 24 (22) | - - | - - |
| As % of total EU banking assets (incl. Norway, the UK) | 65% | 60% | 70% | 70% | 70% |
| EBA sample selection criteria (according to the methodology notes of EU- wide stress tests)* | Top national ranking; at least 50% of assets on country level incl. largest subsidiaries; | Top national ranking; at least 50% of assets on the country level; highest level of consolidation | Top national ranking; at least 50% of assets on the country level; highest level of consolidation | Min. EUR 30 bn. in assets; highest level of consolidation | Min. EUR 30 bn. in assets; highest level of consolidation |
| Two scenarios (baseline and adverse) over the time horizon | 2 years | 2 years | 3 years | 3 years | 3 years |
| Hurdle rate** (adverse scenario) | 6% Core Tier1 ratio | 5% CET1 ratio | 5.5% CET1 ratio | No explicit hurdle rate | No explicit hurdle rate |
| Two scenarios (baseline and adverse) over the time horizon | 2 years | 2 years | 3 years | 3 years | 3 years |

* EU-wide stress test methodology notes.

** The table shows the key hurdle rates for banks to pass in adverse scenario. All data is taken from the official stress test reports available on the EBA website. For the purpose of calculation of the buffer, we applied regulatory hurdle rate 5.5% also for the stress test round in 2016.

Table C: Descriptive statistics and mapping of the instrumental variable buffer

| C.1 Distribution of the IV BUF in the entire sample | | | | |
|--|--------------------|-----------------|--------------------|-----|
| | Percentiles | Smallest | | |
| 1% | -0.0736 | -0.12989 | | |
| 5% | -0.0162 | -0.12145 | | |
| 10% | 0.00019 | -0.1142 | Obs | 560 |
| 25% | 0.0199 | -0.1106 | Sum of Wgt. | 560 |

| | | | | |
|-----|---------|----------------|------------------|--------|
| 50% | 0.03873 | | Mean | 0.0449 |
| | | Largest | Std. Dev. | 0.0598 |
| 75% | 0.05967 | 0.311297 | | |
| 90% | 0.08563 | 0.490185 | Variance | 0.0036 |
| 95% | 0.11781 | 0.555669 | Skewness | 4.0883 |
| 99% | 0.29901 | 0.618207 | Kurtosis | 34.407 |

C.2 Statistics of the IV BUF per year

| Year | mean | sd | min | max | N |
|------|----------|----------|----------|----------|-----|
| 2011 | 0.029293 | 0.02393 | -0.03823 | 0.085795 | 70 |
| 2012 | 0.021668 | 0.029784 | -0.06912 | 0.086418 | 70 |
| 2013 | | | | | 0 |
| 2014 | 0.061232 | 0.072268 | -0.1106 | 0.618207 | 110 |
| 2015 | 0.049635 | 0.069575 | -0.12145 | 0.555669 | 110 |
| 2016 | 0.039324 | 0.068394 | -0.12989 | 0.490185 | 110 |
| 2017 | 0.059431 | 0.048625 | -0.02099 | 0.311297 | 51 |
| 2018 | 0.051473 | 0.051473 | -0.07728 | 0.299014 | 51 |

C.3 Data mapping of instrumental variable “BUF” for the period 2011-2018

| EBA Stress Test Round | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|-----------------------|------|------|------|------|------|------|------|------|
| 2011 | 90 | | | | | | | |
| 2014 | | | | 123 | | | | |
| 2016 | | | | | | 51 | | |
| Banks in our sample | 70 | | | 110 | | 51 | | |

Source: EBA published results and own calculation. The Figure depicts the mapping of the data relevant to the projected capital gap/surplus that is a basis for the calculation of the instrumental variable BUF. We show the number of stress-tested banks on the grey area and a corresponding number of banks in our sample below in Figure.

Table D. Results of the estimation of ATE, ATET and ATENT of structural equations (Probit-OLS, Probit-2SLS, Direct-2SLS) with instrumental variable

| VARIABLES | Dependent Variables Annual Change | | | | | | | | | | | |
|------------|-----------------------------------|-------------|------------|-------------|-------------|------------|-------------|-------------|------------|-------------|-------------|-------------|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| RISK | RISK | RISK | RISK | RWA | RWA | RWA | NPL | NPL | NPL | LOAN | LOAN | LOAN |
| probit-ols | probit-2sls | direct-2sls | probit-ols | probit-2sls | direct-2sls | probit-ols | probit-2sls | direct-2sls | probit-ols | probit-2sls | direct-2sls | direct-2sls |

| | | | | | | | | | | | | |
|--------------------|----------|----------|-----------|-----------|-----------|-----------|---------|----------|---------|---------|---------|----------|
| W_ | -0.076** | -0.040** | -0.194*** | -0.375*** | -0.203*** | -0.905*** | 0.006 | 0.003 | 0.000 | -0.162* | -0.078 | -0.156 |
| | (0.035) | (0.018) | (0.068) | (0.097) | (0.059) | (0.258) | (0.017) | (0.009) | (0.023) | (0.097) | (0.050) | (0.141) |
| _ws_TALog | | 0.006 | 0.054*** | | 0.010 | 0.249*** | | -0.002 | 0.000 | | -0.005 | 0.043 |
| | | (0.005) | (0.019) | | (0.015) | (0.073) | | (0.002) | (0.007) | | (0.014) | (0.039) |
| _ws_LARc | | -0.040 | -0.272** | | -0.162 | -1.238*** | | -0.030 | -0.018 | | -0.061 | -0.098 |
| | | (0.065) | (0.109) | | (0.199) | (0.413) | | (0.032) | (0.024) | | (0.181) | (0.220) |
| _ws_DLR | | 0.052 | 0.347*** | | -0.095 | 1.318*** | | -0.012 | 0.005 | | -0.126 | 0.086 |
| | | (0.043) | (0.110) | | (0.132) | (0.420) | | (0.023) | (0.050) | | (0.121) | (0.216) |
| _ws_COST | | 0.012 | -0.009 | | 0.001 | 0.001 | | 0.037*** | 0.008* | | 0.108* | 0.075*** |
| | | (0.021) | (0.012) | | (0.064) | (0.045) | | (0.009) | (0.004) | | (0.059) | (0.026) |
| _ws_NIM | | -0.003 | -0.032*** | | 0.043*** | -0.107*** | | 0.002 | -0.000 | | 0.027* | -0.017 |
| | | (0.005) | (0.010) | | (0.016) | (0.038) | | (0.003) | (0.004) | | (0.015) | (0.022) |
| _ws_CAR | | -0.222 | 0.130 | | -1.572*** | 0.842*** | | -0.021 | -0.024 | | -0.612 | 0.045 |
| | | (0.157) | (0.080) | | (0.493) | (0.306) | | (0.067) | (0.035) | | (0.441) | (0.169) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | 0.086** | -0.033 | -0.031 | 0.089 | 0.076 | 0.190* | 0.028* | 0.029** | 0.025** | 0.005 | 0.026 | 0.169* |
| | (0.039) | (0.025) | (0.021) | (0.080) | (0.087) | (0.113) | (0.015) | (0.014) | (0.012) | (0.079) | (0.068) | (0.091) |
| Observations | 2,039 | 2,039 | 2,039 | 2,035 | 2,035 | 2,035 | 1,808 | 1,808 | 1,808 | 2,051 | 2,051 | 2,056 |
| Instrument | | | | | | | | | | | | |
| Variable: | | | | | | | | | | | | |
| $\Delta CET1RxBUF$ | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| ATE | | | | | | | | | | | | |
| ATE | -0.0757 | -0.0398 | -0.194 | -0.375 | -0.203 | -0.905 | 0.0064 | 0.0026 | 0.0003 | -0.162 | -0.0778 | -0.156 |
| ATET | -0.0531 | -0.0280 | -0.0952 | -0.304 | -0.183 | -0.462 | 0.0027 | -0.0017 | 0.0007 | -0.145 | -0.0890 | -0.0811 |
| ATENT | -0.0831 | -0.0436 | -0.226 | -0.399 | -0.209 | -1.046 | 0.0076 | 0.0040 | 0.0002 | -0.167 | -0.0741 | -0.180 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Potential outcome framework and evaluation of average treatment effects (Cerulli, 2015; Rubin, 2005)

The following methodology describes the potential outcome framework that we employ for assessment of the heterogeneous treatment effect with instrumental variable. It can be formulated in the form of the equation: $y = y_0 + w(y_1 - y_0)$, where y denotes a potential outcome and w is a linear probability function for propensity to be selected into the treatment. According to (Wooldridge, 2010, Ch.21) we can write the observed outcome equation y as:

$$y = \mu_0 + (\mu_1 - \mu_0)w + v_0 + w(v_1 - v_0), \quad (9)$$

where $\mu_g = E(y_g)$ and $v_g = y_g - \mu_0$, $g = 0, 1$. If the conditional mean assumption (Imbens, 2014; Rosenbaum and Rubin, 1983) does not hold then we solve it by applying IV. The appropriate IV z has to satisfy the

properties i.e. the exclusion restriction criteria. If it is a case then we can assert that: $E(v_0|\mathbf{x}, z) = E(v_0|\mathbf{x}) = g(\mathbf{x}) = \mathbf{x}\boldsymbol{\beta}$ which means that $E(v_0|\mathbf{x}, z) \neq 0$. It leads to the regression model having an error term with zero unconditional mean of this type:

$$y = \mu_0 + \tau w + \mathbf{x}\boldsymbol{\beta}_0 + u_0, \quad (10)$$

where $\tau = \tau_{ate}$ and $u_0 = v_0 - E(v_0|\mathbf{x}, z)$. All these conditions bring us to the system of structural equations:

$$\begin{aligned} y_i &= \mu_0 + w_i\tau + \mathbf{x}_i\boldsymbol{\beta} + u_{0i}, \\ \widehat{w}_i &= \eta + \mathbf{q}_i\boldsymbol{\delta} + \varepsilon_i, \\ w_i &= \begin{cases} 1 & \text{if } \widehat{w}_i \geq 0 \\ 0 & \text{if } \widehat{w}_i < 0 \end{cases} \\ \mathbf{q}_i &= (x_i, z_i), \end{aligned} \quad (11)$$

From the Law of Iterated Expectations, the average treatment effect (ATE), average treatment effect on treated (ATET) and average treatment effect on non-treated (ATENT) can be estimated as:

$$\begin{aligned} \tau_{ATE} &= \widehat{\alpha}_{IV} \\ \tau_{ATE}(\mathbf{x}) &= \widehat{\alpha}_{IV} + (\mathbf{x} - \bar{\mathbf{x}})\widehat{\beta}_{IV} \\ \tau_{ATET} &= \widehat{\alpha}_{IV} + \frac{1}{\sum_{i=1}^N w_i} \sum_{i=0}^N w_i (\mathbf{x} - \bar{\mathbf{x}})\widehat{\beta}_{IV} \\ \tau_{ATET}(\mathbf{x}) &= \{\widehat{\alpha}_{IV} + (\mathbf{x} - \bar{\mathbf{x}})\widehat{\beta}_{IV}\}_{(w=1)} \\ \tau_{ATENT} &= \widehat{\alpha}_{IV} + \frac{1}{\sum_{i=1}^N (1-w_i)} \sum_{i=0}^N (1-w_i) (\mathbf{x} - \bar{\mathbf{x}})\widehat{\beta}_{IV} \\ \tau_{ATENT}(\mathbf{x}) &= \{\widehat{\alpha}_{IV} + (\mathbf{x} - \bar{\mathbf{x}})\widehat{\beta}_{IV}\}_{(w=0)} \end{aligned} \quad (12)$$

The average treatment effects can be consistently estimated under the Stable Unit Treatment Value Assumption (SUTVA) (Imbens, 2014; Imbens and Rubin, 2015). In meaning that the potential outcome observation on one unit does not affect the particular assignment of treatments to the other units.

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Univerzita Karlova v Praze, Fakulta sociálních věd

Institut ekonomických studií [UK FSV – IES] Praha 1, Opletalova 26

E-mail : ies@fsv.cuni.cz

<http://ies.fsv.cuni.cz>