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

Karel Janda[a,b] and Oleg Kravtsov[a]
[a]Prague University of Economics and Business
[b]Institute of Economic Studies, Faculty of Social Sciences, Charles University

We investigate how the regulatory stress-test framework in the European Union affects banks' investment decisions and portfolio choices. Using the causal inference and event-study methods, we document a substantial impact of EU-wide stress tests in 2011, 2014, and 2016 on the banks' portfolio strategies. The banks subject to regulatory stress tests tend to structure their portfolios with lower-risk assets, which is reflected in a decline in risk-weighted assets. At the same time, the dynamic of realized risk that is measured by the proportion of non-performing exposure in portfolios remains unaffected. The magnitude of such effect rises with the increase in the size of the banks' assets.

JEL Codes: G20, G21, G28.

1. Introduction

In the post-crisis period, stress testing has emerged as one of the major tools used by regulators to assess the resilience of individual

*We are grateful to the associate editor Linda S. Goldberg and two anonymous referees for insightful comments and suggestions. This article is part of a project that has received funding from the European Union's Horizon 2020 Research and Innovation Staff Exchange program GEOCEP under the Marie Sklodowska-Curie grant agreement No. 870245. We also acknowledge support from the Czech Science Foundation (grant 22-19617S). The paper represents the authors' personal opinions and does not necessarily reflect the views of their institutions. The authors are responsible for all errors and omissions. Corresponding author (Kravtsov): Department of Banking and Insurance, Faculty of Finance and Accounting, Prague University of Economics and Business, W. Churchilla 4, 13067 Praha 3, Czech Republic. E-mail: oleg-kravtsov@outlook.com.

institutions and financial systems to economic shocks. Since 2010, the Committee of European Banking Supervisors (CEBS) and the European Banking Authority (EBA) have been conducting 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 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 behavior at the singular institutional level (Acharya, Berger, and Roman 2018; Bassett and Berrospide 2018; Pierret and Steri 2019). The forward-looking nature of the stress-test exercises that allows projecting the amount of 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 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 2020). This paper addresses this issue by exploring in depth the time-dynamic causal effect of regulatory stress tests on a bank's investment strategies 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 a substantial impact on other financial intermediaries, thus affecting the real economy.

The focus of our article is on the investigation of changes in the portfolio structures and investment decisions associated with EU-wide stress-test rounds in 2011, 2014, and 2016.[1] We develop a novel empirical strategy within the econometric framework of the causal inference and event study. The heterogeneity of treatment effect is studied at the group and individual unit level and by taking into

[1]The results of EBA stress tests in 2018 are not considered in our analysis, because they are out of scope of our econometric approach, i.e., we compare forward-looking values with historical data.

consideration a variation in timing of the events. The difference-in-difference estimator in generalized form has been employed to evaluate the treatment effect in time-dynamic settings. Next, we study the heterogeneity of treatment effect on individual unit level by employing an instrumental variable (IV) that is manually constructed on the basis of the publicly available results of EBA regulatory stress-test rounds in 2011, 2014, and 2016 and methodologies of Acharya, Engle, and Pierret (2014) and Eber and Minoiu (2016).

We find that regulatory stress testing contributes to a decline of risk density of portfolios, which is 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 alter a mix of assets in their balance sheets towards less capital-intensive areas, while the overall risk remains seemingly unchanged. On the other hand, we observe that the enhanced regulatory scrutiny prevents the stress-tested banks from engaging in risky behavior, i.e., increased risk in a portfolio or excessive loan growth. Thus, the regulatory stress testing fulfills its objective of promoting prudent risk-management practices. Our results are robust in alternative specifications such as modeling with an instrument variable in the continuous form within the treated sample and based on the alternative samples.

Our contribution to the literature is twofold. First, 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, Correa, and Lee 2020; Cohen and Scatigna 2016; Cortés et al. 2018; Goldstein and Sapra 2014; Gropp et al. 2019; Mésonnier and Monks 2014; Pierret and Steri 2019; Schuermann 2014). We extend this literature by providing evidence based on the novel identification strategy with the application of the causal inference methods that allow us to isolate the effects of regulatory stress tests from other capital regulations and analyze the heterogeneity of treatment effect in time-dynamic settings. Second, our results have important implications for the supervisors, since we shed some light on the dynamic of bank behavioral responses to the regulatory scrutiny of stress tests.

The rest of this article is structured as follows: Section 2 reviews the prior literature; Section 3 provides details on the data set, the sample matching strategy, and description of the variables; Section 4 elaborates on the identification strategy and describes the empirical methods; Section 5 presents results of empirical methods; Section 6 provides a series of robustness checks for testing the results of baseline specification; Section 7 summarizes the results and implications and concludes the study.

2. Literature Review

Our study relates to several strands of literature. The first strand of literature focuses on post-crisis capital regulations in a broad sense and the channels of transmission of the additional capital requirements, regulatory monitoring costs, and their implications on the individual bank's conduct. This literature predicts that the regulatory stress tests can lead to the adaptive portfolio and investment strategies, also affecting the credit supply.

Acharya, Berger, and Roman (2018) study the risk-taking behavior of U.S. banks subject to the regulatory stress tests since the Dodd-Frank Act. They find that the stress-tested banks reduce credit supply, particularly to risky borrowers, with the aim of decreasing their credit risk. Gropp et al. (2019) indicate that banks increase their capital ratio by decreasing their risk-weighted assets ex ante facing the increase in capital requirements. The studies of Cortés et al. (2018) indicate 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 of credit to risky borrowers. Pierret and Steri (2019) indicate that stress tests effectively prevent excessive risk-taking by bringing stricter supervision on the investment portfolios of stressed banks. However, 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. Among the primary channels of the transmission are the adjustments in banks' balance sheets or portfolio composition structure (Bräuning and Fillat 2020). They suggest that while the individual portfolios of the largest U.S. 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. 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 results of Bassett and Berrospide (2018) show that among the stress-tested banks in the United States, 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 second strand of literature deals with questions of optimal disclosure and asymmetric information associated with it. 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 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. Some researchers also point out the issues with the interpretation of published results of stress tests, e.g., it might imply an official endorsement of the health of an institution (Schuermann 2014) or implicit assurance that regulators would in some way absorb losses in excess of the stress-test estimates (Flannery 2013).

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; Flannery, Hirtle, and Kovner 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. Goncharenko, Hledick, and Pinto (2018) show that systemically important banks gain the least from the disclosure and bear the highest cost in terms of its volatility.

Finally, another strand of literature is related to the discussions on the calibration of methodologies of stress tests from a macroprudential and microprudential perspective (Andersen et al. 2019; Fungacova and Jakubik 2013; Gersl et al. 2013; Stádník, Raudeliūnienė, and Davidavičienė 2016; Witzany 2017a). In the EU, EBA stress tests are run under the static balance sheet assumption. In the so-called constrained bottom-up stress test (European Banking Authority 2016; European Central Bank 2019), maturing assets and liabilities are replaced with similar financial instruments, and management actions are restricted. 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 (Budnik et al. 2019; Busch, Drescher, and Memmel 2017). They highlight the importance of the initial level of bank capital and bank asset quality.

3. Data

3.1 Data Set 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 the regulatory stress test belong to the control group and are referred to as "non-stressed banks."

For compiling the treated group, we use the published results of stress tests in 2011, 2014, and 2016 conducted by the EBA. The financial institutions are located in the EU and EEA (European Economic Area) countries with Single Supervision Mechanism and Denmark, Norway, Sweden, and the United Kingdom. The number of banks that participated in separate stress tests was 90 in 2011, 123 in 2014, and 51 in 2016. The earlier results of the regulatory stress test

Figure 1. EU-Wide Stress Tests Timeline and Our Sample

observation window

EBA Stress-Tests Dates: (from announcement to published results)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
30.10.2018–02.11.2018									x	
05.11.2015–31.07.2016							x			
31.01.2014–26.10.2014					x					
13.01.2011–17.07.2011		x								
18.06.2010–25.07.2010	x									
# banks tested	91	90			123		51		48	
of which in our sample	n/a	70			110		51		n/a	

Note: 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 tests 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 are taken from the official stress-test reports available on the EBA website.

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, this could distort the consistency of findings from analysis at the individual bank level. The entire data set covers the period 2011–18 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 eight 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 but that it is evolving over the time horizon, e.g., from a stronger effect during the first rounds to the weaker effect of the last rounds. This serves as a basic assumption for our identification strategy discussed later in the paper.

Figure 1 depicts the timeline of stress tests and observational window, as well as the statistics on our participating banks.

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 Bureau van Dijk BankFocus. Similarly, the sample of the control observations is obtained from the database Bureau van Dijk 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. The EU-wide regulatory stress tests were run at the highest level of consolidation, thus we exclude the subsidiaries of the multinational banking groups.[2] By doing a manual check of the data, we find a number of banks that were merged, divested, or liquidated over the period 2011–18. We purge them from our data set along with the banks reporting substantially missing data or errors—for example, due to changes in the ownership, level of consolidation, etc. As a result of all these modifications, we obtain the final sample of 442 bank units. This includes 111 stress-tested banks in the treated group and the control group of 332 units that never took part in the EBA stress tests. The effect of removal of the merged, divested, and liquidated banks results in a reduction of the sample by approximately 5 percent.

The choice of the control group is critically important for estimating the causal effects to ensure the randomized setup. 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; and (iii) geography of entities in the treated group.

The participation in the EU-wide stress-test exercise was not randomly assigned to the banks. The selection into the sample is based on several criteria, such as the size of the assets of the banking group and highest ranking for systemically important institutions on the national level (more detailed in Table A.3 in the appendix). EBA selection criteria result in the stress-tested banks being on average larger than non-stressed banks. In our sample, the minimum size of total assets for the banks which participated in the EU-wide

[2]In the case of countries—e.g., Latvia, Luxembourg, Malta, Slovenia—where the bank sector is small and mostly represented by subsidiaries of large multinational banking groups which are systemically important on the national level, we include them in the control group to provide a more feasible counterfactual on the country level.

stress test in 2011 was approximately EUR 500 million (as in the case of a Spanish bank, 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, Lepetit, and Tarazi 2013). In order to capture the single effect of regulatory stress tests 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. The final result is tested by performing the t-test for two groups of units, depicted in 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 the banks in the treated group.[3] 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 the t-test on significance in the difference in mean. The full list of banks in the treated and control group is provided in the online appendix (at http://www.ijcb.org).

3.2 Variables and Descriptive Statistics

3.2.1 Outcome Variables

The outcome variables of our interest are the risk indicators that are commonly used as measures of portfolio riskiness: the annual change in the "risk density," which is a ratio of the risk-weighted assets to total assets (RWATA), and the annual change in the ratio of non-performing loans to total portfolio (NPL) (Beck, Jakubik, and Piloiu 2015; Berger and Bouwman 2012; Camara, Lepetit, and

[3]The treated group comprises banking institutions from the following countries: Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, and the United Kingdom.

Table 1. Descriptive Statistics of Treated (stress-tested) and Control (non-stressed) Groups in the Sample

	Panel A			Panel B					
	All Banks			Treated	Control		t-test		
Variables	**Mean**	**Std. Dev.**	**Median**	**Mean**	**Mean**	**Difference**	**t-stat**	**p-value**	**Sig.**
Risk and Performance Metrics									
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	***
Bank Characteristics									
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	***
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				

Note: In Table A.1 in the appendix we provide more detailed definitions of the variables and sources of information.

Tarazi 2013; Janda and Kravtsov 2018). 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 (ΔNPL) is an annual change in the ratio of non-performing loans to the total loans on the balance sheet. Our third dependent variable (ΔLOAN) denotes the annual change in loan volumes and captures the effect on the banks' lending activities. It describes the portfolio growth and can be analyzed in the context of applied risk indicators. For example, the changes in loan volumes are associated with standard banking operations and may reduce the NPLs ratio, but an abnormal growth rate would indicate too risky a strategy that eventually could result in deterioration of the portfolio quality (Zhang et al. 2016).

3.2.2 Observable Bank Characteristics (Controls)

The participation in EU-wide stress-test exercises was assigned according to the size of assets on the single bank unit level and also on the national level to cover the total assets of 50 percent of the country banking sector. 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. Hence, 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) (Teplý, Majstřík, and Pečená 2015). NIM reveals the amount of money that a bank is earning in interest on loans compared with the amount it is paying in interest on deposits. Net interest margin varies among banks depending on their business models. Similarly, the cost-to-income ratio differentiates between institutions emphasizing 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 the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR), they are penalized for the dependence on shorter-term funding; therefore the funding and liquidity structure is an important characteristic to account for. The level of capitalization is measured in our analysis by the capital adequacy ratio (CAR), which is a ratio of regulatory capital to total risk-weighted assets. Similarly, many of the larger-size banks are systematically important institutions, which means that they are subject to additional capital requirements. These banks are required to maintain higher capitalization levels, e.g., countercyclical capital buffers, systemic risk buffers, etc. These are not a part of the core capital, i.e., common equity tier 1 (CET1) ratio, and therefore we consider them as heterogeneous bank capital characteristics.

3.3 Effect of Capitalization on Portfolio Adjustments in Treated and Control Groups

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 behavior by banks (Aggarwal and Jacques 2001; Berger and Bouwman 2012; Besanko and Kanatas 1996; Furlong and Keeley 1991; Jeitschko and Jeung 2005; Shrieves and Dahl 1992), we derive our hypothesis that the hypothetical capital shortfall or extra capital implied from the supervisory stress tests must have an influence on the banks' conduct. In addition, the bank units subject to regulatory stress tests face enhanced scrutiny through the qualitative assessments of portfolio and capital plans. This monitoring and supervision effect of regulatory stress tests should incentivize banks to follow more prudent business practices when making decisions regarding investment and portfolio risk management.

In our sample, we also observe that the changes in capitalization (CET1 ratio) affect both the stress-tested banks (treated) and the non-stressed banks (control). In both groups, it is evident that the increase in the capital ratio is associated with a decline in risk density (RWATA), which is a ratio of risk-weighted assets to total assets. In Table 2, the coefficients in columns 1 and 2 exhibit the statistical significance for the outcome variable of the annual changes in risk density ratio (RWATA). Such effect is mostly due to the 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 the calculation of risk-weighted assets (both ratios share the component), e.g., from the standard approach to the internal-rating-based (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. This preliminary analysis implies that the regulatory stress tests can affect portfolio structure and investment decisions ex ante through the difference in capital planning processes. So our task is to build up the 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 portfolio structures contingent on the variation in the timing of the rounds of the stress tests.

4. Empirical Strategy

The primary goal of our analysis is to examine the impact of regulatory stress tests on the adjustment strategies in portfolios and changes in investment decisions of the EU banks that were a subject of the regulatory stress tests. We adopt the causal inference methods to estimate a treatment effect in event-study design, based on

Table 2. Changes in Capital Ratio and Portfolio Composition in the Treated and Control Group

	Dependent Variable Annual Change (in pp or %)									
	RWATA Treated	**RWATA Control**	**NPL Treated**	**NPL Control**	**RWA Treated**	**RWA Control**	**LOAN Treated**	**LOAN Control**	**TA Treated**	**TA Control**
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
ΔCET1R	−0.006***	−0.004***	−0.000	−0.000	−0.021***	−0.015**	−0.005**	−0.006*	−0.001	−0.002
	(0.002)	(0.001)	(0.001)	(0.000)	(0.006)	(0.006)	(0.002)	(0.003)	(0.004)	(0.002)
Constant	0.338	0.458***	−0.092	0.051	−1.233	0.527	−2.778***	−1.222*	0.050	−0.047
	(0.521)	(0.139)	(0.262)	(0.075)	(0.973)	(0.935)	(0.686)	(0.642)	(0.076)	(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

Note: In this table, we report the results of the regression model: $\Delta Y_{it} = \alpha_i + \delta_t + \beta_2 \Delta CET1R_{it} + y' \, controls_{it} + \varepsilon_{it}$, where α_i is a unit fixed effect, δ_t is a year fixed effect, and ε_{it} is an i.i.d. error term. The observed outcome ΔY_{it} denotes annual changes in portfolio metrics such as risk density (RWATA), realized risk (NPL), loan volumes (LOAN), and total assets (TA). Importantly, one of our controls is the explanatory variable ΔC_{it} that represents the annual change in common equity tier 1 capital ratio as $\Delta C_{it} = CET1R_{it} - CET1R_{it-1}$. Finally, we control for bank-specific observation characteristics, namely the size of the bank's assets, a level of efficiency, funding and liquidity structure, and capitalization, with more details described in Section 3.2. Robust standard errors are presented in parentheses and statistical significance is denoted as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. The standard errors are clustered on the bank-unit level to alleviate the heterskedasticity bias. To test for multicollinearity issues in this specification, the variance inflation factor (VIF) was computed. The results of the test (all VIFs close to 1) confirm the absence of multicollinearity issues.

the data of the stress-test rounds conducted by the EBA in 2011, 2014, and 2016. Thereby, the inclusion of an individual bank in the EBA regulatory stress test is considered as a treatment effect. Statistically speaking, we aim to explore the heterogeneity of treatment effect that arises from variations in responsiveness to treatment:

- *at the group level* (comparing the stress-tested with non-stress-tested banks);
- *at the individual unit level* (the strength of the capital requirement effect for a single bank); and
- *variation in the timing* of treatment (event study).

To explore the heterogeneity of treatment effect at the *group level* (control versus treated group), we employ the difference-in-difference (DID) estimator in generalized form, whereby the source of causality stems from the comparison between two groups of treated and control before and after the inclusion into the regulatory stress test. The generalized form of DID provides flexibility to control simultaneously for the observable bank characteristics that could plausibly confound the effect of bank capital requirements on the outcome, and the time/unit fixed effects that absorb all unobserved individual and time-invariant factors.

Separately, we study in depth the heterogeneity of the treatment effect at the *individual unit level* with the help of the constructed instrumental variable (IV) "buffer" (BUF). The instrument BUF allows to proxy for the variation in responsiveness of the individual bank to the economic shock that is pre-defined in EBA scenarios. This measure quantifies the capital shortfall or surplus available and, in other words, represents the sensitivity of a bank's portfolio to a hypothetical economic shock. To fulfill its identification function as an instrumental variable (or continuous treatment variable[4]), the measure BUF needs to be exogenous from the outcome of our interest. To address this issue, we exploit the exogeneity of the economic scenarios and thresholds parameters defined by the sole discretion of banking authorities (EBA) for each stress-test round. Across this study, we utilize BUF as a continuous treatment variable or IV in

[4]Depending on the modeling type and its application, the measure "buffer" (BUF) serves as instrumental variable or continuous treatment variable.

interaction terms with historical risk-adjusted capital ratio (CET1 ratio) to highlight the strength of the effect.

The inclusion of the individual banks in the EU-wide stress-test framework is associated with enhanced scrutiny and regulatory monitoring and, in general, higher disclosure requirements and transparency of the portfolio and riskiness. This effect has a substantial contribution (Goldstein and Sapra 2014), so we need to account for it since, naturally, it affects the investment decisions and portfolio choices of the treated banks. The introduced interaction element with historical changes in the CET1 ratio enables us to isolate the impact of enhanced regulatory scrutiny of regulatory stress tests from *non-capital requirements* (Pierret and Steri 2019). To do so, we assume plausibly (see Section 3.3) that the changes in standard capital requirements—or, specifically, the regular capital requirements on the CET1 ratio[5]—affect similarly both the treated and the control group. Thus, the identification comes from the remaining effect in interaction terms with treatment variable or IV while accounting for the observable characteristics and confounding factors.

The next empirical challenge is to provide an unbiased assessment of treatment effect due to the *variation in the timing* of the events. To do so we employ the generalized form of DID estimator adopted to event-study framework. Here we are also motivated by studies (e.g., Glasserman and Tangirala 2016) indicating that the effects of regulatory scrutiny, particularly of the regulatory stress test, are not static and that they are evolving over the time horizon. 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, Rohwer, and Schneider 2019). The overall strategy here is to restrict the pretrends and apply full time-dynamic settings with both unit/time fixed effects for complete sample (control and treated units). Practically, we censor the combined sample to the duration of the group treatment and account for the timing variation in treatment effect,

[5]For more details, see the revised version of "Basel III: A Global Regulatory Framework for More Resilient Banks and Banking Systems" at https://www.bis.org/publ/bcbs189.htm.

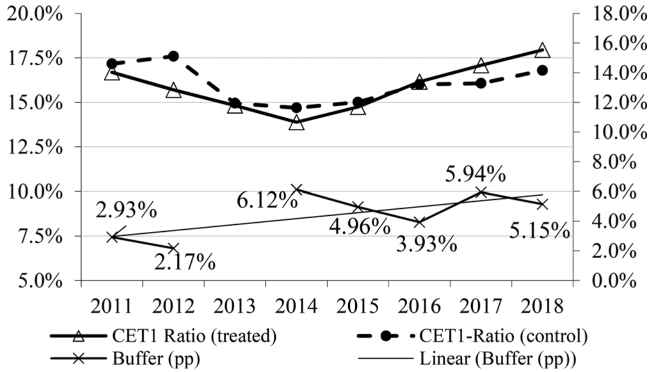
i.e., early or late participants, always or never participated units during the three waves of events, or in our case, the regulatory stress-test rounds. The control group thus consists of never treated and not yet treated units and it provides valid counterfactuals for the group of already treated units. The causal effect of the intervention can be captured more precisely not only by comparing two groups but also by considering the multi-timing of treatment. By doing so, we avoid the misidentification problem due to the extrapolation and negative weights when we employ the generalized DID estimator to the not-restricted sample (Borusyak and Jaravel 2018).

4.1 Measure of Banks' Capital Requirement from the Regulatory Stress Test

In this section, we describe the mechanism of constructing a measure "buffer" (BUF) to quantify the capital requirements from regulatory stress tests or, in other words, the sensitivity of banks' capital to hypothetical shocks. Building upon the methodology of Acharya, Engle, and Pierret (2014) and Eber and Minoiu (2016), we exploit the exogeneity of the economic scenarios and thresholds parameters defined by bank supervision authorities for each stress-test round. We use these factors to calculate the sensitivity of a bank's capital and portfolio to the hypothetical economic shocks as pre-defined in EBA scenarios. To do this, we make use of the published results of EBA stress-test rounds in 2011, 2014, and 2016, and calculate a projected "shortfall" or "surplus" in a stressed capital ratio (we name this measure "buffer" since in our sample we identify a capital surplus for almost all banks in the sample).

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 percent and in the case of the adverse scenario, a minimum CET1 ratio of 5–5.5 percent that is also referred to as the "hurdle rate" in EBA stress-test methodology (see details on the stress tests in Table A.3 in the appendix). Even though from 2016 the hurdle rate is not explicitly referred to in the published results of EBA stress-test rounds, we

Figure 2. CET1 Ratios and Measure BUF for the Period 2011–18



Note: In the figure, we report unweighted average CET1 ratios for both treated and control group.

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.[6]

In practice, we calculate the buffer as a capital surplus or shortfall 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:

$$BUF_{it} = \min\left\{CET1R_{it}^{baseline} - k^{baseline}, CET1R_{it}^{adverse} - k^{adverse}\right\}. \quad (1)$$

The buffer also can be interpreted as extra capital that each bank can employ as a result of the supervisory stress tests usually being 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 shortfall) failed and those banks with a higher buffer (such as approximation value ≥ 0.01) passed the stress-test exercise. Figure 2 shows historical CET1 ratios and

[6]Since EBA stress-test 2016 does not explicitly refer to any hurdle rate, we apply as a benchmark 5.5 percent.

Figure 3. Data Mapping of Instrumental Variable "BUF" for the Period 2011–18

EBA Stress-Test Round	2011	2012	2013	2014	2015	2016	2017	2018
2011	90							
2014					123			
2016							51	
Banks in our Sample	70				106		51	

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

corresponding buffer values, while more detailed descriptive statistics and distributional characteristics are presented in Table A.2 in the appendix. It is worth mentioning that in our sample, we observe on average capital surplus in value of 4 percent (buffer = 0.04) for all samples including three tests rounds. Only in a few cases (less than 5 percent in the sample) did banking institutions report capital shortfall (negative values of buffer), and thus formally they failed the regulatory stress test.

In line with our empirical strategy, we consider the observation window that covers a period from 2011 to 2018. It includes three rounds of stress tests and fits within the timeline of the instrumental variable (the data mapping of the instrumental variable exhibited in Figure 3). The 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. We solve this 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, which effectively leads to a shortfall 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 available estimates of the buffer values, i.e., excluding the year 2013 (only in the models with IV).

The measure BUF serves two purposes: first, this is a non-binary or continuous treatment indicator in specification with treatment effects analysis in Equation (3). Therefore, it reflects the strength of treatment effect from capital requirements of EBA stress tests (as continuous treatment indicator). Second, as an instrumental variable (IV) it helps to isolate the capital requirements from stress tests from other regular capital requirements within the restricted sample of stress-tested banks in Equation (4).

Whether the measure BUF is an instrumental variable or a continuous treatment variable, it should be exogenous from the outcome variable of our interest to fulfill its identification function. A standard criticism of this measure as an identification function is that to some extent it can be endogenous to choices made by the bank (e.g., internal risk models might have the identical scenarios for the economic shocks as those proposed by regulators). Besides, it may be endogenous to unobserved variation in bank investment decisions and capital planning processes due to the publicly available information about methodologies of EBA stress tests. We argue that IV BUF can be exogenous for several reasons—first of all, because the type of scenarios and severity of the economic shocks along with sample-selection criteria are changing every stress-test round and these are defined on the sole discretion of EBA. Hence, it is highly doubtful that these can be influenced by a single bank or a group of banks. In reality, when the scenarios and hurdle rates become known to bankers, the structural changes in portfolio and business models require a longer period of time for such adjustments (projected scenarios for three-year horizons). There is an element of predictability when the processes of stress testing become a standard procedure for the banks. However, there is widely acknowledged concern about the routines and predictability of regulatory stress-test processes and the danger that they will lead banks to optimize their choices for a particular supervisory hurdle and implicitly create new, harder-to-detect risks after a while (Glasserman and Tangirala 2016). If it becomes a case in reality, then it would diminish its value as a practical toolkit in identifying the potential risks of externalities, and hence there is a substantial degree of uncertainty expected to remain in assumptions and scenarios proposed by a banking authority in the future.

4.2 Portfolio Adjustments in Response to the Regulatory Stress Tests

We use a difference-in-difference estimator with the multi-timing treatment to study the bank's portfolio adjustments in response to three rounds of EBA regulatory stress tests. For this purpose, we adopt the event-study setting where units adopt the policy or treatment at a particular point in time and then remain exposed to this treatment at all times afterwards (Athey and Imbens 2018; Callaway and Sant'Anna 2019).[7] In practice, a DID estimator is employed in the generalized form of two-way (unit and time) fixed linear regression model for the panel data. Additionally, we saturate the model with interactions and confounding factors. The baseline specification is defined in Equation (2),

$$\Delta Y_{it}^{obs} = \alpha_i + \delta_t + \tau \cdot W_{it} + \beta \Delta C_{it} + \gamma' X_{it} + \varepsilon_{it}, \qquad (2)$$

and in the interactions of the variable C (capital ratio CET1R) with treatment indicator W (in binary form or with continuous treatment variable BUF from Section 4.1) in Equation (3):

$$\Delta Y_{it}^{obs} = \alpha_i + \delta_t + \tau \cdot W_{it} + \beta (\Delta C \cdot W)_{it} + \gamma' X_{it} + \varepsilon_{it}, \qquad (3)$$

where i represents a bank unit, t is the time period, α_i is a unit fixed effect, and δ_t is a year fixed effect included to control for variation over the time. The indicator of treatment effect W_{it} is taking a binary form of a value 1 for the treated unit and 0 for the unit that was not treated. 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.

The outcome variables of the risk and performance metrics are grouped in vector Y and proxied by annual changes in risk density (RWATA) and its component (RWA), realized risk (NPL), and loan volumes (LOAN). The explanatory variable ΔC_{it} represents an annual change in common equity tier 1 capital ratio as $\Delta C_{it} = CET1R_{it} - CET1R_{it-1}$. The remaining control variables

[7] The Methodological Addendum section in the appendix contains more detailed information on the methodology of average treatment effect analysis with a variation in treatment timing.

X_i are the observable characteristics of the treated and control bank units, namely the size of the bank's assets, a level of efficiency, funding and liquidity structure, and capitalization, as described in Section 3.2. Finally, in these specifications, we assume that the unobserved factor is distributed as $\varepsilon_{it} \sim iid\left(0, \sigma^2\right)$. The aggregate effect of the supervisory stress test on the adjustments in the portfolio is captured in Equation (2). The isolated effect of regulatory scrutiny from other capital requirements is modeled in Equation (3) by the element of the interaction between the binary treatment indicator W_{it} with changes in capital ratio ΔC_{it} or in the alternative as a continuous treatment variable BUF_{it}. It is important to note that in Equation (3), we omit a main effect variable ΔC from the model to isolate the confounding effect of regular bank capital requirements on the outcome variables and to avoid the correlation issues with the other capital-related independent variable specified in the model.

We assume plausibly (see Section 3.3) that the regular bank capital requirements affect both treated and control groups identically, with the following exceptions: (i) intrinsic difference in sensitivities of the portfolio to the hypothetic shock (in interaction with instrumented variable BUF); (ii) other *non-capital driven* effects (in interaction with changes in CET1 ratio), e.g., enhanced regulatory scrutiny and monitoring, or larger transparency and disclosure requirements. Under this assumption, the estimated τ indicates whether the changes in portfolio are associated with the regulatory stress testing in general, while a finding that β is statistically different from zero suggests that the bank's responses in question are associated with regulatory scrutiny or higher capital requirements caused by the regulatory stress tests. If none of the mentioned coefficients is statistically significant except for 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.

At last, we test both specifications on the appropriateness of the linear regression with two-way fixed effects by a specification test for heteroskedasticity (Imai and Kim 2019a, 2019b; White 1980). In Section 6, we provide a series of formal tests of the parallel trend assumption, where the results of the tests confirm the specification's robustness.

5. Results

5.1 Regulatory Stress Tests and Bank Responses

Table 3 reports the results, together with specification tests of the baseline (Equation (2)) and model, with interactions (Equation (3)) for four outcome variables: risk density (RWATA), risk-weighted assets (RWA), realized risk in portfolio (NPL), and loan growth (LOAN). Overall, we observe that the inclusion in the regulatory stress-test framework over the period 2011–18 results in the decline of the risk-weighted assets, while not affecting the other metrics, i.e., realized risk or loan growth. The inclusion is associated with the decline of 0.052 percentage point (column 3) in RWA. The magnitude of the effect is statistically increasing when we include the interaction with changes in the capital ratio (CET1) and instrument variable (IV) buffer "BUF" (in columns 9 and 11). One percentage point of available surplus in hypothetical capital from the regulators' stress tests results in the decline of the risk density (RWATA) by 0.057 percentage point and RWA by 0.282 percent. Thus it provides evidence that the primary channel of adjustments is the bank's concern about the capital-intensive areas in the portfolio in view of targeted capital position. The findings are robust and the estimated coefficients are significant with confidence level 95 percent and 99 percent, and steadily increasing normal and adjusted R^2 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 IV BUF, in columns 5 and 7, 9 and 11, respectively. We document that the separated impact of regulatory scrutiny accounts for the decline in risk density by 0.005 percentage point and risk-weighted assets by 0.014 percentage point, while the effect of higher capital requirements contributes to the decline by 0.057 and 0.282, respectively.

Our results are in line with Acharya, Engle, and Pierret (2014) and Plosser and Santos (2018), who argue that the strong reliance on the stress-test 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. In contrast to Pierret and Steri (2019), we do not observe the negative effect on the lending activities (LOAN),

Table 3. Results of a Regression Model with Heterogeneous Treatment Effect in Time-Dynamic Settings

	Dependent Variables Annual Change (pp and %)											
	RWATA	**NPL**	**RWA**	**LOAN**	**RWATA**	**NPL**	**RWA**	**LOAN**	**RWATA**	**NPL**	**RWA**	**LOAN**
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
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)
ΔCET1R × W					−0.005***	0.001	−0.014***	−0.004				
					(0.002)	(0.001)	(0.005)	(0.003)				
ΔCET1R × W × BUF									−0.057***	0.009	−0.282***	−0.060
									(0.017)	(0.008)	(0.087)	(0.038)
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	Yes	Yes	Yes
Bank 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 Homoskedasticity:												
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

Note: Time effects are adjusted to the dates of the instrumental variable, i.e., we exclude the dummy of the year 2013 from the calculation. Robust standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

columns 4, 8, and 12, as the coefficients are not statistically significant. However, 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 realized risk or portfolio quality (NPL) are not statistically significant in all specifications; see columns 2, 6, and 10. So we conclude that the regulatory stress tests did not have any impact on the write-off strategies or changes in portfolio quality ex ante.

5.2 Heterogeneity within the Sample of Treated Banks

In this section, we study responsiveness to higher capital requirements from regulatory stress tests on the individual banks subject to the EU-wide regulatory stress tests. We conduct this empirical analysis to ensure that the results from previous Section 5.1 are not distorted by strong heterogeneity within the sample of the treated group. We employ the exogenous measure buffer (BUF) as an instrumental variable (IV) (it can be viewed also as a continuous, non-binary treatment variable) to identify the effect of higher capital requirements from regulatory stress tests on the portfolio composition within treated banks. By construction, BUF is a measure quantifying the surplus or shortfall of hypothetically projected stressed capital that is derived from the results of EBA stress-test rounds for participating banks (in Section 4.1 we provide detailed rationale and calculations of this measure).

Instead of attempting to identify a complete set of separate causes, we intend statistically to grasp the more tractable task of identifying the marginal effect of the IV in causal interactions. Using the multiplicative interaction model (Brambor, Clark, and Golder 2006; Golder 2005) or the saturated model (Angrist and Pischke 2009),[8] we estimate the marginal causal effect of projected stressed capital (IV BUF) on the outcome of our interest in the following specification:

$$Y_{it} = \beta_1 C_{it} + \beta_2 BUF_{it} + \beta_3 (C * BUF)_{it} + \gamma' X_{it} + \alpha_i + \delta_t + \varepsilon_{it}, \tag{4}$$

[8] Chapter 3.1.4, "Saturated Models, Main Effects, and Other Regression Talk."

where i and t are the indexes for unit and time period with corresponding α_i and δ_t fixed effects, and ε_{it} is an unobserved component. Specifically, we focus on the analysis of portfolio choices and adjustments as an outcome of our interest Y that is represented by the variable of risk density (RWATA). This indicator can be also interpreted as a strategic decision on the mix of assets in the portfolio with underlying risk characteristics. To assess the contribution and drivers of changes in portfolio, we decompose the risk density ratio and analyze separately its components such as risk-weighted assets (RWA) and total assets (TA). Similarly to previous specifications, we use the annual change in common equity tier 1 capital ratio, $C_{it} = CET1R_{it} - CET1R_{it-1}$, and a vector X of control variables of bank-specific characteristics.

Following Angrist and Pischke (2009) and Frondel and Vance (2009), we estimate the marginal causal effect of C on the expected value of Y that is dependent on the variable BUF if $\beta_3 \neq 0$. Simultaneously, we include bank control variables that could plausibly mitigate the confounding effect of bank capital requirements on the outcome Y and control for time/unit invariant unobserved effects. Under the assumption of the linear functional form of unobserved component $\varepsilon_{it} \sim iid\left(0, \sigma^2\right)$, it can be computed as

$$\frac{\partial Y}{\partial C} = \beta_1 + \beta_3(BUF), \tag{5}$$

where the estimate of the marginal causal effect is given by

$$\frac{\partial^2 Y}{\partial C \partial BUF} = \beta_3. \tag{6}$$

Thus, our model in Equation (4) asserts that the impact of a change in capital C on the outcome of interest Y depends on the value of BUF when we control for the bank-specific observable characteristics X and unit/time-invariant effects. Under plausible assumption (see Section 3.3) that the changes in standard capital requirements (i.e., CET1 ratio) affect both treated (stress-tested) and control group identically, we consider the effect of changes in capitalization on the outcome to be constant also within the treated group.

We expect that IV BUF in interaction with changes in CET1 ratio (β_3) will have a similar sign and statistically significant coefficients as the standalone CET1 ratio (β_1) to confirm the evidence of the bank's responses solely stemming from the scrutiny of the regulatory stress test. In Table 4, we report the results of the specification including IV BUF (columns 1, 3, and 5) and adding the interaction terms (columns 2, 4, and 6) to visualize the process of identification of marginal effect from regulatory stress tests. The coefficients on the standalone independent variable RWATA (−0.005) and its interaction with the instrument variable buffer (−0.057) emphasize that the regulatory stress test leads to the reduction of the portfolio riskiness. It is achieved primarily by decreasing the risk-weighted assets. The coefficients (columns 3 and 4) are statistically significant and with the identical sign for standalone independent variable RWA (−0.017) and in interaction with IV BUF rises (−0.326), while the total assets remain unaffected. The coefficients of changes in CET1 ratio (in column 5) and in interaction with IV BUF (in column 6) are not statistically significant. We can conclude that the inclusion of the banks in the regulatory stress tests leads to a reduction in risk-weighted assets, while seemingly not affecting the total assets. Potentially, this effect can signify the reshuffling of asset structure toward the less capital-intensive areas.

5.3 Size Effects

In this section, we investigate how the size of the banks and systemic importance affect the results of baseline model Equation (2). To perform a check of the results on the sensitivity to the bank size, we narrowed down the sample by excluding (i) the banking institutions with a status of globally systemically important banks (G-SIBs)[9] and, alternatively, (ii) large financial institutions with assets of more than EUR 100 billion.[10]

In Table 5 we present results of the regression model in Equation (2) replicated for these two subsamples. In the sample excluding G-SIBs, we observe the minor effect of heterogeneity due to the systemic important status of financial institutions.

---

[9]List of G-SIBs: Barclays, BBVA, BNP Paribas, Commerzbank, Deutsche Bank, Dexia, Goupe BPCE, Groupe Credit Agricole, HSBS, ING Bank, Nordea, Royal Bank of Scotland, Santander, Societe Generale, Standard Chartered, Unicredit.

[10]EBA classifies the size of financial institution according to their assets: small (below EUR 20 billion), medium (from EUR 20 to 100 billion), and large (above EUR 100 billion).

Table 4. Reaction of the Stress-Tested Banks (treated) to the Regulatory Stress-Test Rounds in 2011, 2014, and 2016

	Dependent Variables Annual Change (Δ in pp or %)					
	RWATA		**RWA**		**TA**	
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
ΔCET1R	−0.005***	−0.003	−0.017**	−0.005	−0.006	−0.000
	(0.002)	(0.002)	(0.008)	(0.007)	(0.006)	(0.008)
BUF	0.014	0.021	0.562**	0.616***	0.260**	0.274**
	(0.062)	(0.060)	(0.225)	(0.217)	(0.129)	(0.131)
ΔCET1R × BUF		−0.057**		−0.326***		−0.118
		(0.026)		(0.087)		(0.115)
Constant	−0.019	−0.024	0.017	−0.008	−0.011	−0.015
	(0.055)	(0.052)	(0.189)	(0.172)	(0.153)	(0.151)
Bank Controls	Yes	Yes	Yes	Yes	Yes	Yes
Unit FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	362	362	362	362	362	362
R-squared	0.141	0.154	0.190	0.249	0.074	0.087
Adjusted R^2	0.107	0.117	0.158	0.217	0.039	0.049
F-test	0.000	0.000	0.000	0.000	0.0086	0.0099

Note: Robust standard errors are in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 5. Regression Results of the Baseline Model Equation (2) on the Subsamples

	Banks with TA < 100 Billion				**Excluding G-SIBs**			
	RWATA (Δpp)	**NPL (Δpp)**	**RWA (Δ%)**	**LOAN (Δ%)**	**RWATA (Δpp)**	**NPL (Δpp)**	**RWA (Δ%)**	**LOAN (Δ%)**
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
W	−0.000	0.010	−0.009*	0.019	−0.012	0.009	−0.047*	0.005
	(0.013)	(0.007)	(0.024)	(0.043)	(0.013)	(0.006)	(0.025)	(0.023)
ΔCET1R	−0.005***	−0.000	−0.015**	−0.006***	−0.005***	−0.000	−0.015***	−0.006**
	(0.002)	(0.001)	(0.006)	(0.002)	(0.001)	(0.001)	(0.005)	(0.003)
Constant	0.644***	−0.093	−0.248	−1.546***	0.601	−0.025	0.046	−1.333**
	(0.232)	(0.178)	(0.738)	(0.467)	(0.204)	(0.161)	(0.594)	(0.637)
Unit FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,594	1,386	1,586	1,605	1,950	1,722	1,945	1,965
R-squared	0.258	0.287	0.382	0.311	0.248	0.275	0.374	0.313
F-test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sample Characteristics	Treated = 65 Units (58%) Control = 298 Units (90%)				Treated = 98 Units (88%) Control = 330 Units (99%)			

Note: Robust standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

In column 7, the coefficient (−0.047) for a treatment effect W is statistically significant for the outcome variable risk-weighted assets (RWA). The size of the effect is slightly less than the coefficient (−0.052) in the full sample (in Table 3). Thus we can conclude that the overall results reiterate those based on the full data set. Remarkably, when we restrict a sample to the total assets up to EUR 100 billion, we observe a significant decline in the size of the effect of regulatory stress tests on the risk-weighted assets. In column 3, we observe that the coefficient for the outcome variable RWA declines to (−0.009) and is less statistically significant (90 percent confidence level). This indicates that the adjustments in the portfolio are more relevant for larger and systemically important institutions, while the smaller-size bank units remain passive and do not adjust their portfolios in response to the scrutiny of regulatory stress tests as much as bigger banks.

We have to note that, in general, the larger banks tend to have more sophisticated risk-management processes and advanced methods in the calculation of risk-weighted assets, e.g., an advanced IRB approach that allows them to capture the riskiness of portfolio more thoroughly and present lower risk weights. Moreover, the larger and systemically important institutions have more incentives to adjustments in the portfolio, since they face the overall higher regulatory scrutiny due to their status, and not necessarily from regulatory stress tests. On the other hand, when we reduce the sample by total assets size further, the number of banks in the treated group reduces disproportionally large in comparison with the control group. The treated group becomes less representative, possibly leading to the misidentification. For example, when we restrict our sample to the banks' units below EUR 100 billion in assets, the treated group reduces almost by half (58 percent of the original treated group). The EBA stress test in 2011 includes many smaller banks, while the test rounds in 2016 consist of the largest financial institutions in the EU including G-SIBs.

6. Robustness Checks

In this section, we provide additional analysis and show that our results are robust to a number of specifications and under alternative assumptions. First, we perform the tests on parallel trend assumption that is underlining and most important for unbiased identification of the DID estimator. Second, we perform an analysis on pre-trend and anticipation factors, and test whether the specifications are sensitive to the functional form assumptions.

6.1 Tests of the Parallel Trends Assumption

The failure of the parallel trend assumption due to diverging trends between treated and control banks is a common threat for the identification of the generalized DID estimators (Callaway and Sant'Anna 2019; Imai and Kim 2019a). In the current setting, a parallel trend assumption implies that the portfolio adjustment strategies of the banks would be the same in the absence of treatment, all else being equal. In this section, we present the results of two alternative tests of the parallel trend assumption. The first test augments the model with bank-specific leads of the treatment variable to detect anticipation effects (Callaway and Sant'Anna 2019). The second test controls for the bank-specific trends in the regression model when there is a concern that the specification is sensitive to functional form assumptions (Lee and Solon 2011; Wolfers 2006).

6.2 Effect of Anticipation and Pre-trends

In this section, we check if there are any ex ante adjustments in portfolio attributable to the anticipation of the event of the treatment. Perhaps banking units began changing their behavior in response to an expectation that they would be "treated" in the future. In other words, we test the extent to which the anticipated capital charge, based on the knowledge from previous regulatory tests, is incorporated into the capital planning process. The underlying assumption for an unbiased estimate of τ in Equation (2) and Equation (3) is that the trends in the outcomes for both control and treated groups in the absence of treatment effect are parallel.

Since the regulatory stress tests were introduced in a staggered manner as in our sample, we examine the parallel trends assumption for all outcome variables using an event-study approach. Following Callaway and Sant'Anna 2019, He and Wang 2017, and Imai and

Kim 2019a, we introduce a stronger version of the conditional parallel trends assumption, which is supposed to hold for all periods t. Namely, we assess the reliability of the parallel trends assumption not only for the pre-treatment periods $e \leq t$ but also for the additional periods where $e > t$, which are post-treatment periods. The proposed testing procedure exploits more information, and therefore it is able to detect a broader set of violations of the stronger conditional parallel trends condition. Specifically, we estimate the following equation:

$$\Delta Y_{it} = \alpha_i + \delta_t + \sum_{k \geq -2, k \neq -1}^{k=2} W_{it}^k \cdot \tau_k + \beta \Delta C_{it} + \gamma' X_{it} + \varepsilon_{it}, \quad (7)$$

where Y_{it} represents the main outcomes of interests for the bank unit i in year t. The dummy variables W_{it}^k jointly represent the assignment of the event, whereby e_i denotes a year when the bank unit i became subject to the regulatory stress tests. We define $W_{it}^{-2} = 1$ if $t - e_i \leq -2$ and 0 otherwise; $W_{it}^k = 1$ if $t - e_i = k$ and 0 otherwise, where $k = 0, 1$; and $W_{it}^2 = 1$ if $t - e_i \geq 2$ and 0 otherwise, while α_i is a unit fixed effect and δ_t is a year fixed effect. Note that, similarly to He and Wang (2017), we omit the dummy $k = -1$ in Equation (7), so that post-treatment effects are relative to the period immediately prior to the start of the regulatory stress test. The parameter of our interest τ_k estimates the effect of enhanced scrutiny of regulatory stress test for years following its occurrence. We include the leads in assignment dummy W in the equation testing whether the treatment affects the outcomes (for up to two years) before they were a subject to regulatory stress tests. In Table 6, we report the results for several outcome metrics in columns 1–4.

A test of the parallel trends assumption shows that the leads of the treatments have no substantial impact on the outcomes, i.e., $\tau_k = 0$ for $k \leq -2$. However, it reveals a slight tendency toward the anticipation factor for the indicators of RWA and NPL. In columns 2 and 3, we observe the coefficients statistically significant at the 90 percent confidence level. This is attributable to the expectation of monitoring and other initiatives, e.g., comprehensive assessment or asset quality review, which are ongoing in parallel over the observed time horizon and can influence the results of the test.

Table 6. Test for the Parallel Trends Assumption

Variables	RWATA (Δpp) (1)	NPL (Δpp) (2)	RWA (Δ%) (3)	LOAN (Δ%) (4)
$\geq$ Two Years Before	−0.041	−0.016*	−0.124*	−0.026
	(0.027)	(0.008)	(0.072)	(0.038)
Year of Event	−0.012	0.007	−0.052**	0.002
	(0.012)	(0.006)	(0.023)	(0.021)
One Year Later	0.009	−0.032	−0.015	−0.039
	(0.019)	(0.025)	(0.043)	(0.038)
Two Years Later	0.052	−0.003	0.080	0.001
	(0.034)	(0.011)	(0.060)	(0.043)
ΔCET1R	−0.005***	−0.000	−0.015***	−0.006**
	(0.001)	(0.001)	(0.005)	(0.003)
Constant	0.599***	−0.008	−0.081	−1.415**
	(0.175)	(0.123)	(0.549)	(0.562)
Bank Controls	Yes	Yes	Yes	Yes
Unit FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	2,039	1,808	2,035	2,056
R-squared	0.265	0.276	0.392	0.344
F-test	0.000	0.000	0.000	0.000

Note: Robust standard errors are in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

6.3 Bank-Specific Trends

In the previous section, we applied an event-study approach for testing on the factor of pre-trends when we adjust for the extrapolation of a linear trend over the pre-treatment and post-treatment periods. This approach provides valid inference only under the assumption that the underlying trend is exactly linear. In this section, we test whether the results of the specification are sensitive to the functional form assumptions. In other words, we test if there is a difference in slope between treatment and comparison groups prior to the intervention. Following Friedberg 1998, He and Wang 2017, and Wolfers 2006, we incorporate a product of bank-specific trends in the baseline model in Equation (2). Specifically, we augment the model by the product $\phi_i \cdot t$ and a quadratic term, $\lambda_i \cdot t^2$, where i is the indicator for banks and t stands for the time dimension:

$$\Delta Y_{it} = \alpha_i + \delta_t + \tau \cdot W_{it} + \beta \Delta C_{it} + \gamma' X_{it} + \phi_i \cdot t + \lambda_i \cdot t^2 + \varepsilon_{it}. \tag{8}$$

In Table 7, we report the results of the regression Equation (8) which includes the unit-specific linear trends in columns 2, 5, 8, and 11 and additionally with unit-specific quadratic trends in columns 3, 6, 9, and 12. After including bank-specific trends, the statistical significance of the coefficients remains unchanged for both the treatment indicator (W) and the indicator of changes in the capital (ΔCET1R). Thus, the magnitude of the effect is negligible. The values of adjusted R-squared are slightly higher (from 0.097 to 0.101) for risk density and (from 0.128 to 0.140) for RWA since data now explain a greater portion of the variation of dependent variables. Concluding, the regression results of the augmented model indicate that the specification is not sensitive to variations in the estimation method and functional form.

7. Discussion and Conclusions

In this article, we investigated the bank's response to the enhanced regulatory scrutiny and additional capital requirements from regulatory stress testing in the EU. Using the econometric approach of event study and causal inference on the data set of the banks subject to EBA stress-testing exercises in 2011, 2014, and 2016, we find evidence of the significant and lasting impact of regulatory stress tests on the portfolio choices and investment strategies. In response to the regulatory EU-wide stress tests, we document a decrease in the riskiness of portfolios mostly attributable to the decline in risk-weighted assets. Simultaneously, we observe that the realized risk of the portfolio measured by non-performing exposure metrics remains unaffected. These findings suggest that regulatory stress tests effectively prevent risky lending by imposing a higher capital charge and, correspondingly, banks adjust their portfolios to the less capital-intensive areas. Overall, we cannot find a negative effect on the lending activities linked to the enhanced regulatory scrutiny of regulatory stress tests. At the same time, the dynamics of changes in CET1 ratio are

Table 7. Test for the Parallel Trends Assumption (Bank-Specific Trends)

Variables	RWATA (Δpp)			RWA (Δ%)			NPL (Δpp)			LOAN (Δ%)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
W_	−0.011	−0.009	−0.011	−0.052**	−0.045**	−0.052**	0.005	0.009*	0.008	0.000	0.000	0.003
	(−0.011)	(−0.011)	(−0.011)	(−0.021)	(−0.022)	(−0.022)	(−0.005)	(−0.005)	(−0.005)	(−0.020)	(−0.020)	(−0.020)
ΔCET1R	−0.005***	−0.004***	−0.005***	−0.015***	−0.015***	−0.015***	0.000	0.000	0.000	−0.006**	−0.006**	−0.006**
	(−0.001)	(−0.001)	(−0.001)	(−0.004)	(−0.004)	(−0.004)	(−0.001)	(−0.001)	(−0.001)	(−0.002)	(−0.002)	(−0.002)
Constant	0.598***	0.573***	0.943***	−0.069	−0.222	1.200**	−0.007	−0.053	0.068	−1.403***	−1.403***	−1.806**
	(−0.157)	(−0.159)	(−0.224)	(−0.497)	(−0.491)	(−0.602)	(−0.111)	(−0.104)	(−0.179)	(−0.498)	(−0.498)	(−0.734)
Bank Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
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	Yes	Yes	Yes
Bank Trends	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Unit*time	—	Yes	Yes	—	Yes	Yes	—	Yes	Yes	—	Yes	Yes
Unit*time^2	—	No	Yes	—	No	Yes	—	No	Yes	—	No	Yes
R^2	0.104	0.105	0.109	0.135	0.140	0.147	0.094	0.107	0.108	0.046	0.046	0.046
Adj.-R^2	0.097	0.098	0.101	0.128	0.133	0.14	0.086	0.098	0.099	0.038	0.038	0.0381
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
No. of Clusters	382	382	382	385	385	385	348	348	348	381	381	381
Obs.	2,039	2,039	2,039	2,035	2,035	2,035	1,808	1,808	1,808	2,056	2,056	2,056

Note: Robust standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

associated with the decline in loan volume growth in our sample for both treated and control groups.

The analysis of the heterogeneity of treatment effect in time-dynamic settings points to the lasting adjustments in the balance sheet and portfolio structures in response to the regulatory stress-test framework. Over the observation window of 2011 to 2018, we find a strong impact on the portfolio's composition that has been distributed evenly over the three waves of regulatory stress-test rounds. We conclude that the business models and portfolio structure have been constantly adapting toward the less risky portfolios and presumably with a less sensitive exposure to an economic shock. This creates concern about the incentivizing toward portfolio shifting to the less capital-intensive assets. In the long run, it could be a prerequisite for systemic risks in the concentration of a certain type of assets or lead to the misguidance on the asset-risk return allocation.

The estimates of the impact of regulatory scrutiny from stress tests indicate strong heterogeneity of the effect size due to the size of financial institution. The larger and systemically important institutions behave differently from smaller counterparts in response to the regulatory policy. The evidence based on the analysis of two alternative subsamples (one excluding the G-SIBs and another restricted to the banks with assets below EUR 100 billion) suggests that the magnitude of the changes in portfolio rise with the size of the assets, while the smaller-size banks do not exhibit a similar pattern of response to the regulatory actions.

This study suggests that the indicated effect of the portfolio adjustment strategies might 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, Drescher, and Memmel (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.

Another important issue which is indirectly derived from our analysis is that the "bottom-up" approach of microprudential stress testing allows the riskiness of assets to be determined on the basis of the bank's internal risk models, which raises the importance of the elaborated and aligned risk model landscape. Clearly, it places an important role for the supervision of model landscape and risk governance within organizations (Stein and Wiedemann 2018) 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).

Drawing on our "ex post" analysis should enable the institutions and regulators to define and calibrate new rules and fine-tune methodologies to account for the bank reactions and portfolio dynamics. From a practical point of view, this study provides a series of methodological tools that allow the evaluation of the distinct impact of the enhanced scrutiny and higher capital requirements on the portfolio and balance sheet adjustments in response to the regulatory actions. As a result, it facilitates a more precise assessment of the existing methodologies and thus leads to improvements in the evaluation of financial system resilience to economic shocks.

Appendix

Methodological Addendum

In our empirical analysis, we employ the generalized difference-in-difference estimator in a form of event study with staggered adoption of treatment (Athey and Imbens 2018; Callaway and Sant'Anna 2019). Let us consider a panel of $i = 1, \ldots, N$ units in which the outcome Y_{it} is observed for the $t = 1, \ldots, T$ 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). We refer to the group of treated units during the same period 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) as in Equation (2):

$$Y_{it}^{obs} = Y_{it}^{\infty} + \sum_{1 \le e \le T} \left(Y_{it}^{e} - Y_{it}^{\infty}\right) \cdot 1\left\{E_i = e\right\}. \tag{A.1}$$

If we denote $\hat{\alpha}^{\text{ols}}, \hat{\tau}^{\text{ols}}, \hat{\beta}^{\text{ols}}, \hat{\gamma}^{\text{ols}}$, then the proposed specification in Equation (2) without interaction with capital changes provides the estimates of ordinary least squares (OLS) (Athey and Imbens 2018; Imbens and Rubin 2015) as follows:

$$\begin{aligned}(\hat{\tau}^{\text{ols}}, \hat{\alpha}^{\text{ols}}, \hat{\delta}^{\text{ols}}, \hat{\gamma}^{\text{ols}}) &= \underset{\tau,\alpha,\delta,\gamma}{\arg\min} \\ &\times \sum_{t=1}^{T}\sum_{i=1}^{N}\{\Delta Y_{it} - \alpha_i - \delta_t - \tau \cdot W_{it} - \beta \Delta C_{it} - \gamma' X_{it}\}^2\end{aligned} \tag{A.2}$$

and with the interaction to the capital changes as in Equation (3), the estimates are

$$\begin{aligned}(\hat{\beta}^{\text{ols}}, \hat{\tau}^{\text{ols}}, \hat{\alpha}^{\text{ols}}, \hat{\delta}^{\text{ols}}, \hat{\gamma}^{\text{ols}}) &= \underset{\beta,\alpha,\delta,\tau,\gamma}{\arg\min} \\ &\times \sum_{t=1}^{T}\sum_{i=1}^{N}\{\Delta Y_{it} - \alpha_i - \delta_t - \tau \cdot W_{it} - \beta(\Delta C \cdot W)_{it} - \gamma' X_{it}\}^2.\end{aligned} \tag{A.3}$$

The final results of $\hat{\tau}^{\text{ols}}$ and $\hat{\beta}^{\text{ols}}$ in Equations (2) and (3), respectively, are consistent with average treatment effect on treated (ATET) and signify a potential causal effect from the enhanced regulatory scrutiny of the stress test. The least-square estimates $\hat{\tau}^{\text{ols}}$ and $\hat{\beta}^{\text{ols}}$ 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 standard DID estimator relies on the restriction that any omitted variables are either time-invariant group attributes or time-varying factors that are unit invariant. Together, these two restrictions supplemented with variation in the timing of the treatment produce a spurious effect and can lead to under-identification issues (Callaway and Sant'Anna 2019; Imai and Kim 2019a). In our modeling we follow the solution to this issue proposed by Athey and Imbens (2018) and Borusyak and Jaravel (2018), and we restrict the pre-trends in "semi-dynamic" settings while keeping the unit and time fixed effects for the complete sample (control and treated units). But to do so, we have to justify the absence of an anticipation factor, so that the event timing becomes randomly assigned and, consequently, the pre-trends and expectations cannot influence the outcome. There are a few points that could provide a sound rationale for this. Due to the complexity of the stress-testing exercise, it is very difficult to judge affront the magnitude of the impact, even though the date is announced, and 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) and Carboni et al. (2017) can also provide supportive evidence for this. Sometimes the inconsistencies and uncertainties on the supervisory side can contribute too (Agarwal et al. 2014).

Table A.1. Definitions and Sources of the Variables

Variables	Definitions	Source
Dependent: Bank Risk and Performance		
ΔRWATA	Annual change of the "risk density" ratio that is a ratio of the risk-weighted assets (RWA) to the total assets (TA)	Orbis/BvD BankFocus
ΔRWA	The growth rate of the risk-weighted assets (RWA)	Orbis/BvD BankFocus
ΔNPL	Annual change of asset quality ratio, calculated as the proportion of bank non-performing loans to total loans. Non-performing loans are loans that are past due for 90 days of more.	Orbis/BvD BankFocus
ΔLOAN	The growth rate of loan volumes	Orbis/BvD BankFocus
Control Variables		
ΔCET1R	Common equity tier 1 (CET1) capital to risk-weighted assets, annual change	Orbis/BvD BankFocus
TA	Log of the bank gross total assets	Orbis/BvD BankFocus
LAR	Bank liquidity structure, calculated as the ratio of bank cash and short-term tradable securities to gross total assets	Orbis/BvD BankFocus
DLR	Funding structure, calculated as the ratio of customer deposits and short-term funding to total liabilities	Orbis/BvD BankFocus
COST	Bank efficiency and proxy for a business model, cost-to-income ratio	Orbis/BvD BankFocus
NIM	Bank efficiency indicator. Net interest margin	Orbis/BvD BankFocus
CAR	Bank regulatory capital to risk-weighted assets	Orbis/BvD BankFocus
Instrumental Variable		
BUF	Instrumental variable calculated as a measure of capital shortfall (or surplus) based on the published results of EBA stress tests	EBA Reports/Website
Dummies and Fixed Effects		
W	Binary treatment variable	
Bank FE	Dummy variable for each of the bank units	EBA Reports/Website
Time FE	Annual year dummy variables for all time periods	

Note: This table reports summary and definitions for the variables in our analysis, and source for all the regression variables.

Table A.2. Descriptive Statistics of the Instrumental Variable "Buffer" (BUF)

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	
Descriptive Statistics of the IV BUF per Year					
Year	**Mean**	**Std.**	**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

Table A.3. Key Facts about the EU-Wide Regulatory Stress Test and Our Sample

	2010	**2011**	**2014**	**2016**	**2018**
Announcement Date	Jun. 18, 2010	Jan. 13, 2011	Jan. 31, 2014	Nov. 5, 2015	Jan. 31, 2018
Release Date	Jul. 26, 2010	Jul. 18, 2011	Oct. 27, 2014	Aug. 1, 2016	Nov. 2, 2018
Competent Authority	CEBS	EBA	EBA	EBA	EBA
No. Banks Tested (of	91	90	123	51	49
which in our sample)	—	(70)	(110)	(51)	—
No. Banks Failed	7	8	24	—	—
(of which in sample)	—	(4)	(22)	—	—
As % of Total EU Banking Assets (incl. Norway, the United Kingdom)	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 billion in assets; highest level of consolidation	Min. EUR 30 billion in assets; highest level of consolidation
Two Scenarios (baseline and adverse) over the Time Horizon	Two Years	Two Years	Three Years	Three Years	Three Years
Hurdle Rate** (adverse scenario)	6% Core Tier 1 Ratio	5% CET1 Ratio	5.5% CET1 Ratio	No explicit hurdle rate	No explicit hurdle rate

*EU-wide stress-test methodology notes.
**The table shows the key hurdle rates for banks to pass in adverse scenario. All data are 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 of 5.5 percent also for the stress-test round in 2016.

References

Abraham, S., and L. Sun. 2018. "Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects." arXiv:1804.05785 [econ].

Acharya, V., R. Engle, and D. Pierret. 2014. "Testing Macroprudential Stress Tests: The Risk of Regulatory Risk Weights." *Journal of Monetary Economics* 65 (July): 36–53. https://doi.org/10.1016/j.jmoneco.2014.04.014.

Acharya, V. V., A. N. Berger, and R. A. Roman. 2018. "Lending Implications of U.S. Bank Stress Tests: Costs or Benefits?" *Journal of Financial Intermediation* 34 (April): 58–90. https://doi.org/10.1016/j.jfi.2018.01.004.

Agarwal, S., D. O. Lucca, A. Seru, and F. Trebbi. 2014. "Inconsistent Regulators: Evidence from Banking." *Quarterly Journal of Economics* 129 (2): 889–938.

Aggarwal, R., and K. T. Jacques. 2001. "The Impact of FDICIA and Prompt Corrective Action on Bank Capital and Risk: Estimates Using a Simultaneous Equations Model." *Journal of Banking and Finance* 25 (6): 1139–60. https://doi.org/10.1016/S0378-4266(00)00125-4.

Ahnert, L., P. Vogt, V. Vonhoff, and F. Weigert. 2018. "The Impact of Regulatory Stress Testing on Bank's Equity and CDS Performance." SSRN Scholarly Paper No. 3179540.

Andersen, H., K. R. Gerdrup, R. M. Johansen, and T. Krogh. 2019. "A Macroprudential Stress Testing Framework." Staff Memo No. 1, Norges Bank.

Angrist, J. D., and J.-S. Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist's Companion.* Princeton University Press.

Athey, S., and G. W. Imbens. 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., and J. M. Berrospide. 2018. "The Impact of Post Stress Tests Capital on Bank Lending." Finance and Economics Discussion Series No. 2018-087, Board of Governors of the Federal Reserve System.

Beck, R., P. Jakubik, and A. Piloiu. 2015. “Key Determinants of Non-performing Loans: New Evidence from a Global Sample.” *Open Economies Review* 26 (3): 525–50. https://doi.org/10.1007/s11079-015-9358-8.

Berger, A. N., and C. H. S. Bouwman. 2012. “How Does Capital Affect Bank Performance During Financial Crises?” SSRN Scholarly Paper No. 1739089.

Besanko, D., and G. Kanatas. 1996. “The Regulation of Bank Capital: Do Capital Standards Promote Bank Safety?” *Journal of Financial Intermediation* 5 (2): 160–83. https://doi.org/10.1006/jfin.1996.0009.

Blossfeld, H.-P., G. Rohwer, and T. Schneider. 2019. *Event History Analysis with Stata*, 2nd ed. Routledge.

Borusyak, K., and X. Jaravel. 2018. “Revisiting Event Study Designs.” SSRN Scholarly Paper No. 2826228. https://doi.org/10.2139/ssrn.2826228.

Brambor, T., W. R. Clark, and M. Golder. 2006. “Understanding Interaction Models: Improving Empirical Analyses.” *Political Analysis* 14 (1): 63–82.

Bräuning, F., and J. L. Fillat. 2020. “The Impact of Regulatory Stress Tests on Bank Lending and Its Macroeconomic Consequences.” SSRN Scholarly Paper No. 3716448.

Budnik, K. B., M. Balatti, G. Covi, I. Dimitrov, J. Groß, I. Hansen, M. Kleemann, et al. 2019. “Macroprudential Stress Test of the Euro Area Banking System.” SSRN Scholarly Paper No. 3414174.

Busch, R., C. Drescher, and C. Memmel. 2017. “Bank Stress Testing under Different Balance Sheet Assumptions.” Discussion Paper No. 07/2017, Deutsche Bundesbank.

Calem, P., R. Correa, and S. J. Lee. 2020. “Prudential Policies and Their Impact on Credit in the United States.” *Journal of Financial Intermediation* 42 (April): Article 100826. https://doi.org/10.1016/j.jfi.2019.04.002.

Callaway, B., and P. H. C. Sant’Anna. 2019. “Difference-in-Differences with Multiple Time Periods.” SSRN Scholarly Paper No. 3148250.

Camara, B., L. Lepetit, and A. Tarazi. 2013. “Ex Ante Capital Position, Changes in the Different Components of Regulatory Capital and Bank Risk." Débats économiques et financiers (Economic and Financial Debates) No. 7, Banque de France.

Candelon, B., and A. N. R. Sy. 2015. "How Did Markets React to Stress Tests?" Working Paper No. 15/75, International Monetary Fund.

Carboni, M., F. Fiordelisi, O. Ricci, and F. S. S. Lopes. 2017. "Surprised or Not Surprised? The Investors' Reaction to the Comprehensive Assessment Preceding the Launch of the Banking Union." *Journal of Banking and Finance* 74 (January): 122–32. https://doi.org/10.1016/j.jbankfin.2016.11.004.

Cohen, B., and M. Scatigna. 2016. "Banks and Capital Requirements: Channels of Adjustment." *Journal of Banking and Finance* 69 (Supplement 1): S56–S69.

Cortés, K., Y. Demyanyk, L. Li, E. Loutskina, and P. E. Strahan. 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., and X. D'Haultfœuille. 2018. "Two-Way Fixed Effects Estimators with Heterogeneous Treatment Effects." arXiv:1803.08807 [econ].

Eber, M., and C. Minoiu. 2016. "How Do Banks Adjust to Stricter Supervision?" SSRN Scholarly Paper No. 2662502.

European Banking Authority. 2016. "EBA Launches 2016 EU Wide Stress Test Exercise." Press Release, February 24. https://www.eba.europa.eu/eba-launches-2016-eu-wide-stress-test-exercise (accessed September 15, 2019).

European Central Bank. 2019. "The Evolution of Stress-testing in Europe." https://www.ecb.europa.eu/press/key/date/2019/html/ecb.sp190904_2~4c8236275b.en.html (accessed September 23, 2019).

Flannery, M., B. Hirtle, and A. Kovner. 2017. "Evaluating the Information in the Federal Reserve Stress Tests." *Journal of Financial Intermediation* 29 (January): 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. 2370104.

Friedberg, L. 1998. "Did Unilateral Divorce Raise Divorce Rates? Evidence from Panel Data." *American Economic Review* 88 (3): 608–27.

Frondel, M., and C. Vance. 2009. "On Marginal and Interaction Effects: The Case of Heckit and Two-Part Models." SSRN Scholarly Paper No. 1493156. https://doi.org/10.2139/ssrn.1493156.

Fungacova, Z., and P. Jakubik. 2013. "Bank Stress Tests as an Information Device for Emerging Markets: The Case of Russia." *Czech Journal of Economics and Finance* 63 (1): 87–105.

Furlong, F. T., and M. C. Keeley. 1991. "Capital Regulation and Bank Risk-taking: A Note." (Reprinted from *Journal of Banking and Finance.*) *Economic Review* (Federal Reserve Bank of San Francisco) (Summer): 34–39.

Georgescu, O. M., M. Gross, D. Kapp, and C. Kok. 2017. "Do Stress Tests Matter? Evidence from the 2014 and 2016 Stress Tests." SSRN Scholarly Paper No. 2968952.

Gersl, A., P. Jakubik, T. Konecny, and J. Seidler. 2013. "Dynamic Stress Testing: The Framework for Assessing the Resilience of the Banking Sector Used by the Czech National Bank." *Czech Journal of Economics and Finance* 63 (6): 505–36.

Glasserman, P., and G. Tangirala. 2016. "Are the Federal Reserve's Stress Test Results Predictable?" *Journal of Alternative Investments* 18 (4): 82–97. https://doi.org/10.3905/jai.2016.18.4.082.

Golder, S. N. 2005. "Pre-electoral Coalitions in Comparative Perspective: A Test of Existing Hypotheses." *Electoral Studies* 24 (4): 643–63. https://doi.org/10.1016/j.electstud.2005.01.007.

Goldstein, I., and H. Sapra. 2014. "Should Banks' Stress Test Results be Disclosed? An Analysis of the Costs and Benefits." *Foundations and Trends in Finance* 8 (1): 1–54. https://doi.org/10.1561/0500000038.

Goncharenko, R., J. Hledik, and R. Pinto. 2018. "The Dark Side of Stress Tests: Negative Effects of Information Disclosure." *Journal of Financial Stability* 37 (August): 49–59. https://doi.org/10.1016/j.jfs.2018.05.003.

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., T. Mosk, S. Ongena, and C. Wix. 2019. "Banks Response to Higher Capital Requirements: Evidence from a

Quasi-Natural Experiment." *Review of Financial Studies* 32 (1): 266–99. https://doi.org/10.1093/rfs/hhy052.

He, G., and S. Wang. 2017. "Do College Graduates Serving as Village Officials Help Rural China?" *American Economic Journal: Applied Economics* 9 (4): 186–215. https://doi.org/10.1257/app.20160079.

Imai, K., and I. S. Kim. 2019a. "On the Use of Two-way Fixed Effects Regression Models for Causal Inference with Panel Data."

———. 2019b. "When Should We Use Unit Fixed Effects Regression Models for Causal Inference with Longitudinal Data?" *American Journal of Political Science* 63 (2): 467–90. https://doi.org/10.1111/ajps.12417.

Imbens, G. W., and D. B. Rubin. 2015. *Causal Inference for Statistics, Social, and Biomedical Sciences.* Cambridge University Press.

Janda, K., and O. Kravtsov. 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 (4): 5–24. https://doi.org/10.18267/j.efaj.216.

Jeitschko, T. D., and S. D. Jeung. 2005. "Incentives for Risk-taking in Banking — A Unified Approach." *Journal of Banking and Finance* 29 (3): 759–77. https://doi.org/10.1016/j.jbankfin.2004.05.028.

Kupiec, P. 2019. "Policy Uncertainty, Financial Stability, and Stress Testing." SSRN Scholarly Paper No. 3363866.

Lee, J. Y., and G. Solon. 2011. "The Fragility of Estimated Effects of Unilateral Divorce Laws on Divorce Rates." *B.E. Journal of Economic Analysis and Policy* 11 (1): 1–11.

Mésonnier, J.-S., and A. Monks. 2014. "Did the EBA Capital Exercise Cause a Credit Crunch in the Euro Area?" Working Paper No. 491, Banque de France.

Petrella, G., and A. Resti. 2013. "Supervisors as Information Producers: Do Stress Tests Reduce Bank Opaqueness?" *Journal of Banking and Finance* 37 (12): 5406–20.

Pierret, D., and R. Steri. 2019. "Stressed Banks." SSRN Scholarly Paper No. 3066403.

Plosser, M. C., and J. A. C. Santos. 2018. "Banks' Incentives and Inconsistent Risk Models." *Review of Financial Studies* 31 (6): 2080–2112. https://doi.org/10.1093/rfs/hhy028.

Roengpitya, R., N. Tarashev, K. Tsatsaronis, and A. Villegas. 2017. "Bank Business Models: Popularity and Performance." Working Paper No. 682, Bank for International Settlements.

Schuermann, T. 2014. "Stress Testing Banks." *International Journal of Forecasting* 30 (3): 717–28. https://doi.org/10.1016/j.ijforecast.2013.10.003.

Shrieves, R. E., and D. Dahl. 1992. "The Relationship between Risk and Capital in Commercial Banks." *Journal of Banking and Finance* 16 (2): 439–57. https://doi.org/10.1016/0378-4266(92)90024-T.

Stádník, B., J. Raudeliūnienė, and V. Davidavičienė. 2016. "Fourier Analysis for Stock Price Forecasting: Assumption and Evidence." *Journal of Business Economics and Management* 17 (3): 365–80. https://doi.org/10.3846/16111699.2016.1184180.

Stein, V., and A. Wiedemann. 2018. "Risk Governance: Basic Rationale and Tentative Findings from the German Banking Sector." In *Current Issues in Corporate Social Responsibility: An International Consideration, CSR, Sustainability, Ethics & Governance*, ed. S. O. Idowu, C. Sitnikov, D. Simion, and C. G. Bocean, 97–110. Springer International Publishing. https://doi.org/10.1007/978-3-319-70449-4_7.

Teplý, P., M. Majstřík, and M. Pečená. 2015. *Bankovnictví v teorii a praxi / Banking in Theory and Practice*. E-book. Knihkupectví Karolinum.

Vozková, K., and P. Teplý. 2018. "Determinants of Bank Fee Income in the EU Banking Industry — Does Market Concentration Matter?" *Prague Economic Papers* 27 (1): 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 (4): 817–38. https://doi.org/10.2307/1912934.

Witzany, J. 2017a. "A Bayesian Approach to Backtest Overfitting." SSRN Scholarly Paper No. 3002503.

———. 2017b. "Credit Risk Management." In *Credit Risk Management: Pricing, Measurement, and Modeling*, 5–18. Springer International Publishing. https://doi.org/10.1007/978-3-319-49800-3_2.

Wolfers, J. 2006. "Did Unilateral Divorce Laws Raise Divorce Rates? A Reconciliation and New Results." *American Economic Review* 96 (5): 1802–20. https://doi.org/10.1257/aer.96.5.1802.

Wooldridge, J. M. 2012. *Introductory Econometrics: A Modern Approach*, 5th ed. South-Western College Pub.

Zhang, D., J. Cai, D. G. Dickinson, and A. M. Kutan. 2016. "Nonperforming Loans, Moral Hazard and Regulation of the Chinese Commercial Banking System." *Journal of Banking and Finance* 63 (February): 48–60.