Journal of Corporate Finance 79 (2023) 102387

Contents lists available at ScienceDirect

Journal of Corporate Finance

journal homepage: www.elsevier.com/locate/jcorpfin

Liability taxes, risk, and the cost of banking crises

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ARTICLE INFO

Editor: Scott Baker

JEL classification:
G21
G30
G32

Keywords:
Financial sector taxation
Banks
Capital structure
Asset risk

ABSTRACT

This study investigates the effects on risk and financial stability of the taxes on bank liabilities introduced across European countries after the global financial crisis. Using a difference-in-differences setup, we show that banks responded to the implementation of liability taxes by reducing their interbank exposure, and by increasing both equity, at least in the short term, and the risk weight of their assets. When we consider these adjustments in a microsimulation model for bank portfolio losses, we find that liability taxes reduce risk in the banking sector and could therefore decrease the cost of crises.

1. Introduction

In the aftermath of the 2008 global financial crisis, several European countries introduced taxes on bank liabilities (also called *bank levies*). By exempting banks' own capital and customer deposits, levies increase the relative cost of risky debt for banks. They therefore ultimately aim to reduce the externalities of bank funding on systemic risk (Shin, 2010). In some cases, the tax receipts were explicitly used to provide funding for bank recovery and resolution (Buch et al., 2016).

Banks may respond in several different ways to the introduction of taxes on liabilities. We focus on three possible balance sheet adjustments: i) the equity ratio; ii) interbank exposure; and iii) portfolio risk. The first part of the paper describes banks' behavioural reaction to the levies, exploiting their staggered introduction in a difference-in-differences setup. We find robust evidence of balance sheet adjustment along these three dimensions. We are ultimately interested in the implications of these taxes for risk, and therefore also estimate their direct impact on standard measures of systemic risk (Acharya et al., 2012; Acharya et al., 2017; Brownlees and Engle, 2017) in the same regression framework. We find that bank levies reduce the contribution of individual banks to systemic risk.

In the second part of the paper, we use a bank portfolio microsimulation model to assess the implications of bank levies for the costs to the public purse of systemic crises (Langedijk et al., 2015; Benczur et al., 2017). We use the behavioural parameters from the main econometric analysis, and calculate counterfactual bank balance sheets to obtain a distribution of losses for individual banks through

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https://doi.org/10.1016/j.jcorpfin.2023.102387
Received 15 December 2021; Received in revised form 23 January 2023; Accepted 6 February 2023
Available online 15 February 2023
0929-1199/

Monte Carlo simulations. We find that bank levies act to incentivise bank capitalisation and reduce exposure on the interbank market, and therefore decrease the public finance costs of banking crises. However, they might also induce banks to hold more risky assets. Overall, the former effect predominated in our simulations, suggesting that levies have a stabilising effect on the financial system. However, when the increase in asset risk weight is large, bank levies result in higher losses than the no-levy counterfactual. While we take a non-normative stance in highlighting intended and potential unintended effects of liability taxes, our analysis provides useful indications of the desirable features of this type of corrective taxation.

Our paper relates to recent studies that have investigated the effects of taxation on banks' behaviour. In response to taxes, banks can alter their pricing strategies (Lin and Pennacchi, 2018) and pass the costs of taxes onto borrowers, particularly groups that are 'locked-in', by increasing their interest rate spreads (Capelle-Blancard and Havrylchyk, 2017). A growing number of studies have suggested that, by changing relative prices, taxes also influence the size and composition of banks' balance sheets, and, ultimately, their risk profile.[1] Corporate taxation is a significant determinant of bank capital structure because it provides relief for interest payments without exempting the return on equity (Keen, 2011; Horvath, 2013; De Mooij and Keen, 2016; Pennacchi, 2019; Fatica et al., 2020; Gambacorta et al., 2021). Corporate tax hikes are associated with higher leverage also in the financial sector (Heider and Ljungqvist, 2015; Schandlbauer, 2017; Milonas, 2018). Similarly, Schepens (2016) and Celerier et al. (2020) find that mitigating the tax bias in favour of debt through an allowance for corporate equity leads to better capitalised banks.

Devereux et al. (2019) study the impacts of taxes on bank liabilities using a cross-country panel. They find that levies on bank borrowing have increased both banks' reliance on equity and the risk profile of their investment. This result is consistent with the findings of Celerier et al. (2020), who show a shift in bank portfolios away from securities and towards loans. In an early evaluation of the German bank levy, Buch et al. (2016) have shown that taxed banks reduced lending and increased deposit rates to attract more tax-exempt funding. However, they do not find any significant change in bank funding structure in response to increased financing costs. Bremus et al. (2020), investigating the interaction between regulatory levies and corporate taxes, find that the former result in lower bank leverage ratios only when the tax bias from profit taxes is not excessive.

In the same spirit as Devereux et al. (2019), we examine the effects of liability taxes on bank balance sheet structure for a panel of banks headquartered in Europe. We focus on behavioural reactions along several dimensions that are relevant for individual and aggregate risk. In addition to standard measures of funding and asset risk, we also consider bank liability structure as a crucial variable that can be adjusted after the implementation of levies. Other significant differences concern the econometric methodology and sample selection, with our analysis spanning a longer period. This allows us to account for both short-term and medium-term adjustments. The paper also contributes to the literature on bank levies by evaluating their ultimate impact on risk and the cost of severe bank crises using a microsimulation model for bank losses (Langedijk et al., 2015; Fatica et al., 2020).

The remainder of the paper is as follows. Section 2 briefly describes bank liability taxes and develops the hypotheses to be tested. Section 3 presents the econometric approach and results. Section 4 introduces the microsimulation model for banking losses, and develops the simulation exercise. Finally, Section 5 concludes.

2. Taxes on bank liabilities and their expected impact

In the aftermath of the global financial crisis, bank levies were widely advocated as a policy instrument that could serve two purposes. First, the additional revenue raised from the banking sector would partly compensate for the sizable fiscal expenses incurred by governments in advanced economies to support ailing financial institutions (International Monetary Fund, 2010). Second, by targeting liabilities, levies would discourage banks from taking unnecessary risks through excessive indebtedness (Roe and Tröge, 2016).

Levies would therefore strengthen the effects of bank capital requirements, contributing to financial stability, as confirmed by the empirical literature. Higher bank capital reduces the risk of bank distress and insolvency, and substantially improves the probabilities of surviving financial crises (e.g., Beltratti and Stulz, 2012; Cole and White, 2012; Berger and Bouwman, 2013; Fahlenbrach et al., 2012). Liability taxes may also partially replace minimum capital requirements, especially when these regulatory provisions are only playing a secondary role in determining capital ratios for large banking organisations. For instance, Berger et al. (2008) find evidence of excess capital, i.e., target capital levels above the regulatory minima, which is actively managed by banks.

Between 2008 and 2012, several European countries introduced levies to tax bank liabilities. These taxes may be differentiated by maturity or counterparty, and are mostly net of 'safe' items, such as equity and insured deposits. In terms of tax design, liability taxes have either a flat rate (Belgium, Sweden) or a progressive rate structure (Austria, Germany). Annex 1 shows the main elements of tax design. By raising the cost of risky borrowing, liability taxes incentivise banks to rely more on their own capital. Tax design normally considers bank characteristics that affect financial stability, such as size and interconnectedness. In practice, systemically important institutions are taxed more heavily, and smaller ones are either exempt or taxed at reduced rates. In some countries, revenues from liability taxes are explicitly earmarked to finance a bank resolution fund rather than accruing to the general budget.

Our interest lies in the implications of liability taxes for risk and, ultimately, for the cost of banking crises. We therefore investigate adjustment of bank balance sheet items with an immediate bearing on bank risk: equity ratios, interbank deposits and regulatory asset risk.[2] These channels of adjustment are then considered in the micro-simulation exercise in the second part of the paper. Given their design, we hypothesis that liability taxes induce a number of changes in bank balance sheets.

[1] Chronopoulos et al. (2019) that the introduction of a bank levy in Australia decreased the stock returns and shareholder value of taxed banks.

[2] We do not consider the issue of bank pricing behaviour.

Liability taxes are primarily expected to enhance bank capitalisation, because they decrease the relative cost of alternative funding sources, especially equity. In any equilibrium where banks are funded through a combination of equity, deposits and debt, changing relative prices leads to a rebalancing of bank capital structure until the costs of different funding instruments are equalised again at the margin. The impact of taxation on bank capital structure is documented in several studies. Devereux et al. (2019) find evidence of increased equity ratios for banks after the introduction of liability taxes. The Belgian Allowance for Corporate Equity, which reduces the favourable tax treatment of debt under corporate income tax, has shown similar effects (Schepens, 2016; Celerier et al., 2020). Schandlbauer (2017) finds that increases in the state-level corporate income tax rates, which raise the marginal benefit of the tax relief for debt, also affect the capital structure decisions of US banks. We therefore formulate the following testable hypothesis:

Hypothesis 1. Liability taxes increase bank capitalisation.

Liability taxes are normally levied on the riskier components of bank funding. The most relevant source of funding available to the banking sector is retail deposits of household savers. Hahm et al. (2013) classify retail deposits as core liabilities, with other components labelled as noncore liabilities. The composition of bank liabilities changes over the financial cycle. Credit booms are normally characterised by an increase in non-core liabilities, because rapid expansion of credit may only be funded by attracting short-term funding. This, however, creates refinancing risk, which may lead to disruptive liquidity runs (Diamond and Dybvig, 1983). Even if the individual bank's funding decision is made considering the bank's exposure to refinancing risk, the system-wide implications are not internalised by individual institutions (Perotti and Suarez, 2011). The global financial crisis showed that noncore liabilities may prove extremely volatile and therefore increase financial fragility. In the post-crisis debate, a tax on non-core liabilities was advocated as a prudent way to dampen the financial cycle (Shin, 2010). In practice, several European liability taxes reflect this view, because they explicitly target specific types of liabilities, including short-term deposits and deposits from banks. Moreover, within the broad class of retail deposits, those covered by insurance are normally tax-exempt. Overall, by changing relative prices, bank levies are also expected to affect the composition of banks' non-equity funding (Sundaresan and Wang, 2014). Our analysis focuses on interbank liabilities, which play a pivotal role in the spread of risk across the banking system because of contagion effects. Against this background, our second testable hypothesis is:

Hypothesis 2. Liability taxes reduce banks' reliance on interbank funding.

In perfect capital markets, a change in banks' capital structure should not affect their portfolio allocation. However, prudential regulation and other forms of government intervention, such as implicit and explicit guarantees, break the segmentation between assets and liabilities in banks' balance sheets. Capital requirements explicitly require portfolio risk to be matched with an adequate level of equity capital. The introduction of liability taxes is therefore also likely to exert an indirect impact on the riskiness of bank assets. However, the direction of the adjustment is ambiguous, and depends on whether liability and asset risk are substitutes or complements. If banks balance bankruptcy cost with other benefits of debt financing at the margin, then an increase in bank capital lowers the disutility of risk, which incentivises investment in more risky assets. Theoretically, this result stems from banks acting like risk-averse competitive portfolio managers, which would structure their balance sheets to maximise the expected utility of their financial net worth, taking prices and yields as given (Koehn and Santomero, 1980; Kim and Santomero, 1988).[3] In a stylised model (Rochet, 1992) with costly equity and binding capital requirements, Celerier et al. (2020) show that introducing a liability tax can lead to a shift in bank portfolio composition if regulatory risk weights do not perfectly reflect the riskiness of each asset. By contrast, an alternative view emphasises the implications of capital structure for managerial incentives and moral hazard (Demsetz et al., 1997). This suggests that more equity could result in more disciplined risk-taking, and therefore be associated with a safer asset portfolio, because moral hazard problems caused by limited liability are attenuated. In this case, funding and portfolio risk would be complements. The literature has highlighted other channels through which bank capital has risk-reduction effects. Coval and Thakor (2005) propose a model in which bank capital is needed to bridge the beliefs gap between rational intermediaries and pessimistic investors. A minimum level of capital would be necessary for intermediaries to provide any liquidity transformation at all, and therefore to assure the viability of banks, as opposed to merely attenuating asset-substitution moral hazard. A number of papers have recognised that capital may contribute positively to bank value. Holmstrom and Tirole (1997) suggest that capital induces banks to monitor borrowers and therefore also improves borrowers' access to credit from both banks and the capital market. Allen et al. (2011) develop a one-period model in which both equity capital and loan rates provide incentives to monitor, thus mitigating the limited liability problem that banks face due to their extensive reliance on deposit-based financing. Competition in the credit market may operate as a disciplining device from the asset side of banks' balance sheets, inducing banks to hold more capital than the regulatory minimum. The reason is that borrowers prefer lower interest rates and higher capital as they do not bear its cost. In a dynamic framework, Mehran and Thakor (2011) suggest that capital has the important role of increasing the future survival probability of the bank, which in turn enhances the bank's monitoring incentive. Bank capital therefore has both a direct positive effect on monitoring incentives and a reinforcing indirect effect via an elevated survival probability. In their framework, market discipline coming from the asset side induces banks to hold positive levels of capital as a way to commit to monitoring, and therefore attract borrowers. Our third testable hypothesis is therefore:

[3] Similarly, Devereux (2014) shows that substitution between funding risk and asset risk exists when banks maximise overall risk subject to regulatory constraints. In this case, they are effectively choosing between combinations of funding and asset risk that leave them at exactly the required ratio of capital to risk-weighted assets. A liability tax that raises the cost of debt therefore induces banks to choose a different combination with less funding risk and more asset risk.

Table 1
Number of banks and observations, by year.

	2008	2009	2010	2011	2012	2013	2014	Bank-year observations
Non-taxed	2578	2578	2500	2095	2088	2094	2125	16,058
Taxed	0	0	78	483	489	484	453	1987
Total	2578	2578	2578	2578	2577	2578	2578	18,045

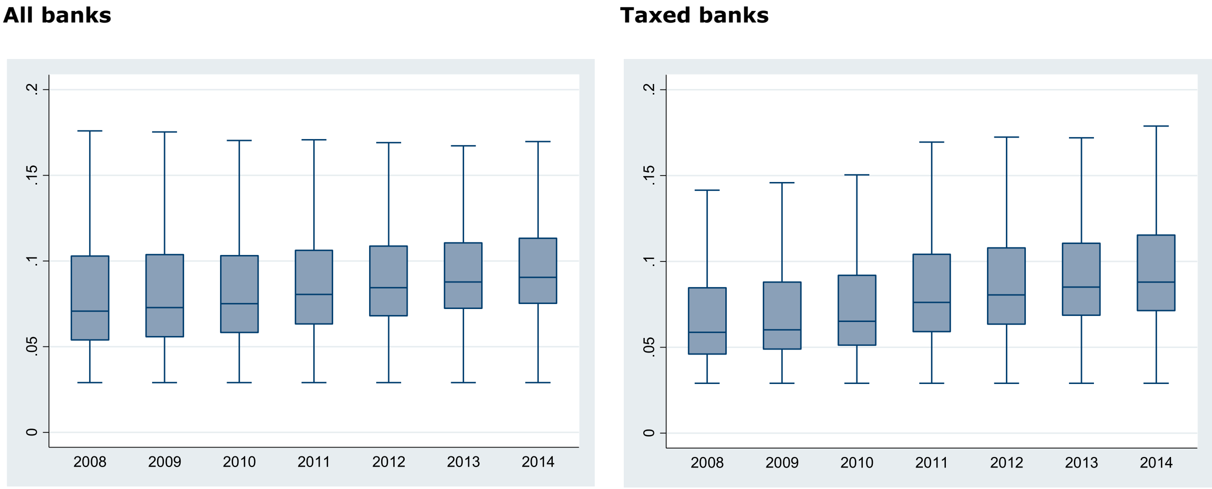

Fig. 1. Equity ratios.

Hypothesis 3. liability taxes affect risk taking on the asset side of banks' balance sheets.

In the next section we empirically test our three hypotheses in a difference-in-differences approach.

3. Econometric analysis

3.1. Data

We draw bank data from the Bankscope database compiled by Bureau Van Dijk.[4] We focus on annual balance sheet and income statement information of banks headquartered in Europe in the period 2008–2014.[5] We restrict our analysis to active banks reporting positive values for total assets and total liabilities for the whole sample period. We use data on an unconsolidated basis.[6] Our initial sample comprises up to 2578 European banks, and a total of 18,045 bank-year observations.

Table 1 shows the composition of our sample, distinguishing between banks subject to liability taxes and those that are outside the scope of these taxes. Up to 20% of all banks observed in the different years are taxed. Overall, 11% of the observations relate to taxed entities. Our sample include a majority of cooperative banks (56% of observations), with 23% of observations on savings banks and 16% commercial banks. The remaining 5% relates to bank holdings, real estate and mortgage banks, and specialised governmental credit institutions. The bulk of taxed entities are commercial banks and savings banks, 40% and 27% of taxed observations.

3.2. Dependent variables

To evaluate the impact of the liability taxes on bank risk-taking, we focus on three channels of adjustment: (i) the equity ratio; (ii) asset risk, measured using the risk-weighted asset density; and (iii) the share of interbank deposits in total liabilities. We compute the

[4] The database is regularly used in cross-country analyses of banking systems (e.g., Demirgüc-Kunt and Huizinga (2001), Demirgüç-Kunt and Huizinga (2010), Gropp and Heider (2010), Chiorazzo and Milani (2011), Huizinga et al. (2014), Bertay et al. (2016), Capelle-Blancard and Havrylchyk (2017) and Devereux et al. (2019) among others.

[5] We exclude France, Hungary, Slovenia and Ireland from the analysis because the levies introduced there are inherently different from the Pigovian type of tax that is the focus of this study.

[6] Liability taxes are imposed on individual banks. Following Devereux et al. (2019), we use consolidated statements to identify the legal incidence of the tax only for banks headquartered in U.K. and the Netherlands, where the taxes apply at group level. However, we use the corresponding unconsolidated data in both the regression and the microsimulation exercise.

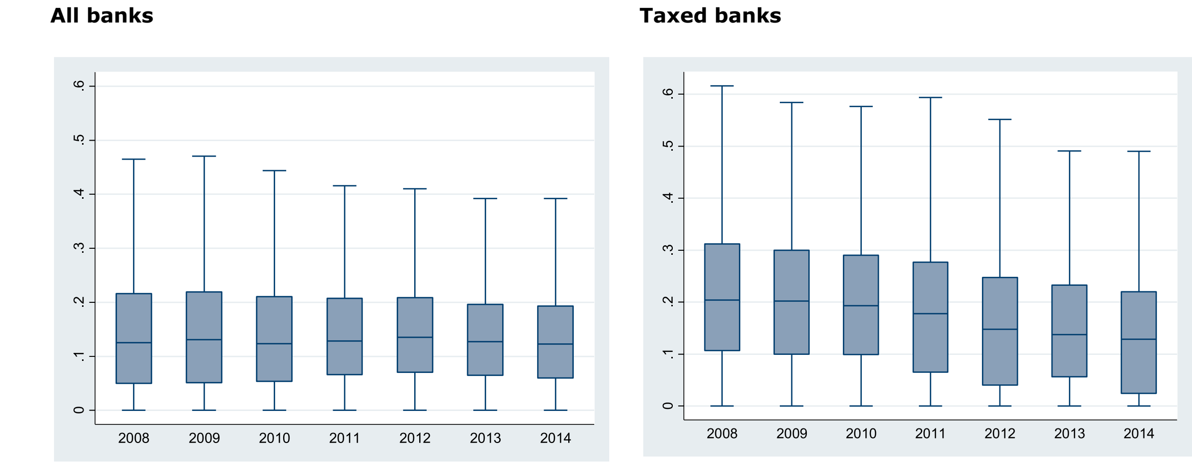

Fig. 2. Interbank exposure.

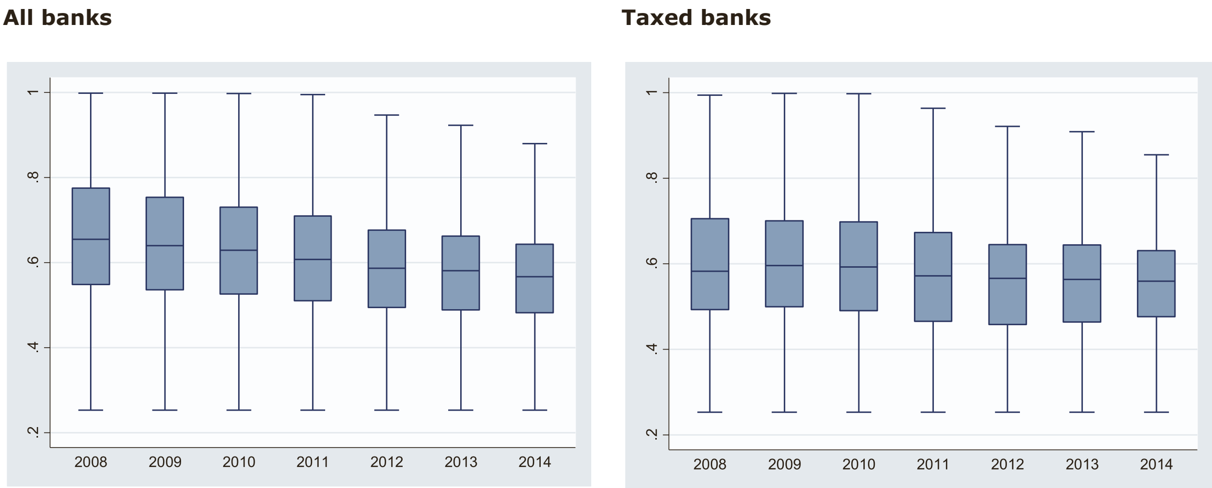

Fig. 3. Regulatory risk weights.

equity ratio as bank equity divided by total assets, both at book value.[7] The equity ratio is a measure of solvency, because it gives an indication of the bank's ability to meet its obligations and absorb unexpected losses. Fig. 1 shows the evolution of the equity ratios over time for all the banks in our sample (left-hand panel) and for the banks subject to taxes on liabilities (right-hand panel). We observe an increase in the median equity ratio in the cross-section of banks over time. This is not surprising, given the process of deleveraging that took place in the European banking sector after the crisis as part of a more general balance sheet restructuring (Bologna et al., 2014). However, the plot shows a more marked increase in the equity ratios of taxed banks than other institutions.

The next step is to evaluate whether liability taxes change the composition of bank funding. For the purpose of our simulation exercise, we are mainly interested in the interbank market, which amplifies bank-specific shocks by spreading them across the whole system. We use deposits from other banks as a proxy of bank interconnectedness. Inter-bank linkages substantially expanded until the financial crisis, but have reduced in the post-crisis years, particularly across borders (European Central Bank, 2017). We therefore calculate the variable *Share of interbank deposits* as the ratio between the deposits from other banks and total liabilities. Deposits from other banks included both deposits and short-term placements from other banks, and cash owed to banks under repurchase agreements. Fig. 2 shows that the median share of deposits from other banking institutions is quite stable in our sample. Looking only at the banks subject to liability taxes, however, there is a clear downward trend in the variable. Taxed banks experienced a reduction in the median share of liabilities coming from interbank deposits from 21% in 2011 to around 17% in 2014.

Finally, the third outcome variable used in our analysis is the density of risk-weighted assets (RWA), computed as the ratio between RWA and total assets. The RWA density is a measure of the average relative risk of banks' operations under the criteria defined by the

[7] To mitigate the impact of outliers, we trim all relevant bank-specific variables at the 2nd and 98th percentile.

solvency regulation.[8] Fig. 3 shows the evolution of the median RWA density of all banks (left-hand panel) and taxed banks only (right-hand panel) in our sample. There is a downward trend in both series, particularly at the beginning of the sample period. A similar pattern emerges for taxed banks, although less pronounced. Ultimately, in which direction and to what extent liability taxes affected bank balance sheets remains an empirical question for our difference-in-differences model. We illustrate our econometric approach in the next section.

3.3. Empirical design

3.3.1. The model

We estimate the impact of liability taxes on bank behaviour by exploiting their staggered introduction. In line with Heider and Ljungqvist (2015), Schandlbauer (2017) and Milonas (2018), we use a difference-in-differences approach and estimate variants of the following model:

$$\Delta y_{ict} = \alpha_1{}' \Delta x_{ict-1} + \alpha_2{}' \Delta W_{ct} + \alpha_3{}' \Delta Z_{ict-1} + \beta_0 T_{ict} + \eta_c + \mu_t + \varepsilon_{ict} \quad (1)$$

where Δ is the first difference operator. Thus, Δy_{ict} measures the change in the outcome variable(s) of interest for bank i in country c at time t, the reference year when the tax change takes place. This implies that the levies enacted in different years are grouped together. The use of a first difference specification allows us to consider tax rate increases subsequent to the introduction of the levies, notably in Sweden and the UK.

Our variable of interest is T_{ict}, an indicator that takes the value of one if there is a tax increase on bank borrowing in country c at time t, and bank i is effectively subject to the tax, and zero otherwise. The dummy T_{ict} therefore equals one if two conditions are met: a bank tax change takes place in the country and year, and the taxable base of a bank exceeds the allowance threshold, in the countries where tax design envisages tax exemption for smaller intermediaries. The vectors x_{ict-1}, W_{ct} and Z_{ict-1} include standard time-varying determinants of the outcome variables. We include them to ensure that contemporaneous shocks to these variables do not affect the estimated impact of the tax increases. In particular, x_{ict-1} is a vector of bank-level characteristics. We resort to the controls usually employed in the empirical literature on the determinants of capital structure (Rajan and Zingales, 1995; Frank and Goyal, 2009), particularly for banks (Gropp and Heider, 2010). To control for differences in size, profitability and risk, we include the book value of the bank's total assets (in logarithmic form), the return on assets (ROA) as net income over the average value of total assets, and the z-score. We also include a measure of collateral, defined as in Gropp and Heider (2010), which we expect to correlate positively with debt. To avoid simultaneity with the dependent variable(s), we lag all bank-level variables by one year.

The vector W_{ct} contains a number of macroeconomic variables, notably GDP growth rate, inflation, and central banks' reference rates as a measure of the cost of funds in the market. We also controll for regulatory and policy actions in the banking sector through a set of variables included in the vector Z_{ict-1}. At the bank level, we define a dichotomous variable for banks that were part of the stress test exercises conducted by the European Banking Authority (EBA) or subject to comprehensive assessments and capital exercises managed by the European Central Bank (ECB). The dummy takes value one if the bank was subject to stress tests or capital exercises, and zero otherwise. We also account for the financial assistance provided by most European governments to troubled financial institutions to safeguard financial stability and prevent a credit crunch. We keep the breakdown by specific aid instrument, i.e. aid for recapitalisation, support for impaired assets, guarantees on liabilities, and other liquidity measures. We also use only the amounts of aid actually used, as opposed to the maximum available amount, in proportion to the size of the national banking sectors, which we proxied using the value of total assets. The construction of the variables used in the estimations is described in Annex 2.

Using first differences eliminates bank fixed effects, which would naturally be included in the corresponding level equation. Our baseline specification includes country and year fixed effects, indicated with the terms η_c and μ_t. The country dummies allow for heterogeneous trends in the outcome variables across national banking systems, and the time fixed effects control for time-varying shocks common to all the countries. Finally, ε_{ict} is a zero-mean error term that satisfies the standard assumptions. Standard errors are robust to heteroscedasticity and clustered at the bank level. To further capture heterogeneous trends across banks based on their level of capitalisation, we also interact the year fixed effects with equity ratio quintiles. To avoid endogeneity, we define equity ratios for 2008, the beginning of our sample period, before the tax changes took place. Controlling for heterogeneous trends across banks with different level of capitalisation is important because the incentives for banks to change their capital level hinges upon the leeway available within the regulatory constraints. De Mooij and Keen (2016) and Schandlbauer (2017) find that sensitivity to corporate taxation differs systematically between high-risk banks with low capital ratios and low-risk banks with high capital ratios.

[8] Regulatory risk weights are far from perfect measures of true portfolio risk. The risk weights set directly by regulators apply to broad asset classes and therefore only capture portfolio risk in a very crude way. There is also concern that risk weights are subject to manipulation, particularly by the largest intermediaries via the use of internal risk models (Haldane, 2013; Mariathasan and Merrouche, 2014). Berger et al. (2016) find a considerable variation in RWA densities by bank size in Europe for the period 2014–2015. They show that smaller banks report RWA densities that are almost twice as large as those of the largest banks (62.4 vs. 32.9%). This difference may be a consequence of manipulation to understate true portfolio risk. If this is the case, then the observed improvement in a bank's equity ratio does not necessarily reflect a reduction in its real risk. However, the difference in RWA may also be due to different factors, such as bank specialisation, balance sheet structure, the types of assets included in each portfolio, the geographical areas of operation of the bank, and the accounting criteria adopted by each country. However, in spite of the drawbacks of this measure, regulatory risk-weighted assets continue to be used in the banking literature to assess banks' response to financial regulations and policy change (De Mooij and Keen, 2016).

Table 2
Propensity score matching diagnostics and summary statistics.

	Full control group					Treated group			
	Mean	Median	p10	p90	Bias (%)	Mean	Median	p10	p90
Equity ratio $_{t-2}$	10.73	9.91	5.46	17.14	−108.2	7.18	6.85	4.92	9.79
Interbank exposure $_{t-2}$	10.09	7.34	0.40	32.23	53.9	15.53	14.37	5.97	26.17
Asset risk weights $_{t-2}$	68.28	68.37	46.60	88.23	−41.2	62.24	61.26	44.40	80.75
Equity ratio (growth) $_{t-1}$	−0.18	−0.15	−1.89	1.21	71.4	0.45	0.35	−0.13	1.19
Interbank exposure (growth)$_{t-1}$	1.51	0.39	−5.92	8.02	−44.2	−0.27	−0.19	−3.43	2.76
Asset risk weights (growth)$_{t-1}$	−2.78	−2.19	−10.17	4.63	23.8	−1.64	−1.40	−5.41	2.21
Total Assets (growth)$_{t-1}$	5.61	4.28	−7.13	17.26	−32.3	3.17	2.78	−2.04	817
Total liabilities (growth)$_{t-1}$	5.84	4.45	−7.77	18.80	−38.1	2.71	2.28	−2.79	7.99
Loan-to-deposits ratio $_{t-1}$	94.04	91.48	49.76	146.55	−154.7	64.24	65.62	44.32	81.68
Loan-to-deposits ratio $_{t-2}$	96.79	93.63	51.41	150.18	−178.6	63.67	65.06	44.07	80.90
Short term funding (growth) $_{t-1}$	10.65	6.71	−8.99	33.48	−59.8	3.33	2.81	−2.41	8.87
Long term funding (growth) $_{t-1}$	−17.37	0.00	−89.86	53.84	−16.1	−33.35	0.01	−74.70	0.82
Interbank deposits (growth)$_{t-1}$	1.22	0.50	−72.59	73.01	−23.2	−10.76	−7.60	−66.18	40.37

	Matched control group					
	Mean	Median	p10	p90	Bias (%)	Bias reduction (%)
Equity ratio $_{t-2}$	7.62	7.39	4.63	11.12	−13.6	87.4
Interbank exposure $_{t-2}$	17.81	14.69	1.89	40.14	−22.5	58.20
Asset risk weights $_{t-2}$	57.74	55.91	35.68	82.36	30.8	25.3
Equity ratio (growth) $_{t-1}$	0.73	0.65	−0.79	2.92	−30.9	56.8
Interbank exposure (growth)$_{t-1}$	−0.68	−0.34	−8.80	8.37	10.3	76.7
Asset risk weights (growth)$_{t-1}$	−0.22	−0.45	−7.75	10.11	−29.6	−24.0
Total Assets (growth)$_{t-1}$	1.35	0.63	−14.52	18.61	23.9	25.9
Total liabilities (growth)$_{t-1}$	0.56	0.00	−18.19	18.08	25.9	31.9
Loan-to-deposits ratio $_{t-1}$	63.27	62.11	38.70	94.43	3.9	97.5
Loan-to-deposits ratio $_{t-2}$	61.28	60.77	38.70	85.99	9.0	94.9
Short term funding (growth) $_{t-1}$	1.15	0.30	−20.72	20.63	17.8	70.2
Long term funding (growth) $_{t-1}$	23.67	0.00	−82.59	14.45	−9.5	41.1
Interbank deposits (growth)$_{t-1}$	−8.44	−9.94	−68.89	50.92	−4.4	81.1

The table reports summary statistics and matching diagnostics for the main variables used in the propensity score matching. The left hand side part of the upper panel shows the summary statistics for the full control group of non-taxed banks, and the right hand side part shows information for the taxed banks. The lower panel shows the values for the banks selected for the control group. The column 'mean' reports the average value of the variables. Median, p10 and p90 are the values of the 50th, 10th and 90th percentiles, respectively. The columns 'Bias (%)' show the standardised percentage bias between the taxed banks and respectively all banks in the full sample and the banks in the control group. The bias is the % difference of the sample means in the treated and non-treated sub-samples as a percentage of the square root of the average of the sample variances in the treated and non-treated groups (Rosenbaum and Rubin, 1985). The column 'bias reduction (%)' shows the percentage change in this bias after matching. A positive value implies that the averages are lying closer to each other after matching.

We address the concern that the tax variable may pick up pre-existing differential trends in our dependent variables by including additional interaction fixed effects in our main specification. We directly control for country-specific trends by interacting country fixed effects with a linear trend. Following Devereux et al. (2019), we also allow for a more flexible dynamic by interacting year fixed effects with regional dummies, with regions defined by grouping countries with similar banking markets.[9] This definition of regions is somewhat arbitrary, and we therefore consider this as a robustness check for our preferred specification with country-time trends.

3.3.2. Matching

The key identifying assumption for the difference-in-differences approach is the parallel trend hypothesis. It states that, in the absence of the treatment, on average the outcomes for the treated and the control groups would have evolved following parallel paths over time. In practice, this is usually verified by looking at trends before the treatment. An important concern in our case is that there might be significant differences between taxed and non-taxed banks. In the econometric setup, these would lead us to identify a selection effect, rather than a causal impact of liability taxes on balance sheet adjustment. These differences might translate into different trends in equity ratios, interbank exposure and asset risk even in the absence of taxes on borrowing. We address this issue by restricting the control group to banks that are most similar to the taxed entities. We use a propensity score matching procedure to build a control group with similar features to the taxed banks, in terms of observable characteristics in the pre-treatment period (Angrist and Krueger, 1999). We adopt the nearest neighbour matching procedure proposed by Rosenbaum and Rubin (1983), whereby we match up to five

[9] In line with Devereux et al. (2019), we defined four regions: Eastern Europe (Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Romania and Bulgaria), Southern Europe (Spain, Portugal, Greece, Italy, Cyprus and Malta), Northern Europe (Denmark, Sweden and Finland), Central Europe (Austria, Germany, Netherlands, Belgium, France and Luxembourg), and the British Isles (the UK and Ireland).

Table 3
The effect of bank taxes on capital structure and risk.

	(1)	(2)	(3)	(4)	(5)	(6)
	Equity ratio					
Tax increase	0.879***	0.702***	0.713***	0.806***	0.568***	0.489***
	(0.142)	(0.103)	(0.135)	(0.145)	(0.093)	(0.087)
R-squared	0.259	0.287	0.324	0.299	0.369	0.403
	Interbank exposure					
Tax increase	−2.044***	−1.489***	−1.916***	−2.569***	−1.014***	−0.750**
	(0.570)	(0.458)	(0.554)	(0.626)	(0.339)	(0.312)
R-squared	0.225	0.258	0.325	0.267	0.380	0.382
	Asset risk weights					
Tax increase	−0.351	−0.216	0.113	0.174	0.840**	1.052***
	(0.766)	(0.565)	(0.502)	(0.784)	(0.358)	(0.369)
R-squared	0.153	0.164	0.247	0.198	0.283	0.301
Bank controls	Yes	Yes	Yes	Yes	Yes	Yes
Country controls	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Regulatory controls	–	Yes	–	–	Yes	Yes
Capital-time FE	–	–	Yes	–	Yes	Yes
Country-time trends	–	–	–	Yes	Yes	–
Region-time FE	–	–	–	–	–	Yes
Observations	7341	7341	7341	7341	7341	7341

The table presents results of the difference-in-difference estimations of the impact of taxes on bank capital structure and asset risk. Dependent variables are Equity ratio, Interbank exposure (as a share of interbank deposits) and Asset risk weights (as a share of total assets), respectively. Column (1) includes bank-level controls and country controls, in addition to time and country fixed effects. Column (2) adds country-specific regulatory controls. Column (3) controls for heterogeneous trends across banks depending on their level of capitalisation by interacting year fixed effects with pre-treatment (2008) capitalisation quintiles. Column (4) controls for country-specific trends. Column (5) includes regulatory controls, capital-time FE and country-specific trends. Column (6) substitutes the country-specific trends with regional dummies interacted with time FE. Standard errors, robust for heteroscedasticity and clustered at the bank level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

non-treated observations to each taxed bank on the estimated probability of being treated (propensity score). We estimate a logit model with a dummy variable equal to one for banks subject to a levy as dependent variable . The matches are selected on the basis of similarities in observed characteristics, including the first and second lag of the debt-to-asset ratio, the lag of total assets (in logarithmic form) as a measure of size, and the lagged value of asset growth to control for growth effects. To capture the evolution of the structure of liabilities, we use the lagged growth of deposits from banks, and the growth of both deposits and short-term funding, and of long-term funding. We also include the first and second lag of the loan-to-deposits ratio, and the second lag of the equity ratio, the deposits over total liabilities and the risk-weighted asset density. The predicted probabilities of the logit model are then used to match each taxed bank with up to five untaxed banks. The matching is performed with replacement, so each bank in the control group can be matched with more than one taxed bank, in order to improve the accuracy of the matching procedure (Smith and Todd, 2005).

Table 2 shows the outcome of the matching procedure. It presents summary statistics for the period before the introduction of the liability taxes, for the taxed banks, the full group of non-taxed banks and the banks in the control group after the matching procedure. It also includes statistics on the reduction in the differences between the taxed banks and the banks in the control group. We report the bias as the percentage difference of the sample means in the treated and non-treated sub-samples as a percentage of the square root of the average of the sample variances in the treated and non-treated groups (Rosenbaum and Rubin, 1983). As a measure of the quality of the matching procedure, the column "Bias reduction (%)" shows the percentage change in the bias between the matched and the full control group of banks after matching, with respect to the treated banks. A positive value means that the averages are closer to each other after matching. The statistic shows a sizable reduction in the bias for virtually all the variables after the matching procedure.

3.4. Results

This section discusses the results of our difference-in-differences analysis, starting with the main findings, and then providing some robustness checks and further results. These include a direct test of the impact of liability taxes on banks' contribution to systemic risk.

3.4.1. Main results

Table 3 shows the results from the model above on the three variables of interest (equity ratios, interbank exposure and asset risk weights). To ease readability, the table focuses on the coefficient estimates for the dummy indicating the tax increase and does not show the coefficients for the control variables. Standard errors are robust for heteroscedasticity and clustered at the bank level. The baseline specification in column (1) includes bank and country-level controls as well as full sets of country and year fixed effects. We find that the tax increase affects the outcome variables in the expected way. Taxed banks increase their equity ratios and decrease their interbank exposure. The impact on the risk weight of assets is also negative, although it is not statistically significant.

In the second step, we augment the baseline model with the regulatory controls. Column (2) shows that the coefficient estimates are

Table 4
The effect of bank levies on capital structure and risk: large vs. small tax increases.

	(1)	(2)	(3)
	Equity ratio	Interbank exposure	Asset risk weights
Large tax increase $_t$	0.679***	−1.267***	0.854**
	(0.099)	(0.318)	(0.354)
Small tax increase $_t$	0.090	0.085	0.780
	(0.155)	(0.738)	(0.868)
Bank controls	Yes	Yes	Yes
Country controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Regulatory controls	Yes	Yes	Yes
Capital-time FE	Yes	Yes	Yes
Country-time trends	Yes	Yes	Yes
Observations	7341	7341	7341
R-squared	0.370	0.381	0.283

The table presents results of the difference-in-difference estimations of the impact of taxes on bank capital structure and asset risk, parsing between small (below the median) and large (above the median) tax increases. Dependent variables are Equity ratio column (1); Interbank exposure (as a share of interbank deposits) (column 2); and Asset risk weights, as a share of total assets) (column (3), respectively. The model includes bank-level and country variables, including country-specific regulatory controls. In addition, they include time and country fixed effects, the interaction between year fixed effects with pre-treatment capitalisation quintiles, and country-specific time trends. Standard errors, robust for heteroscedasticity and clustered at the bank level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

qualitatively similar. The coefficient for asset risk weights remains statistically insignificant. Column (3) controls for heterogeneous trends across banks depending on their level of capitalisation by interacting year fixed effects with pre-treatment capitalisation quintiles. The coefficient estimates, and their statistical significance, are barely affected by the additional controls. In column (4), we include interactions between a linear trend and country dummies. This directly addresses the concern that the dummy for the tax increase might be capturing the fact that banks exposed to it were for some reason on different trajectories than other banks. The results for the equity ratio and the interbank exposure are quantitatively and qualitatively similar to the baseline. Without country-specific trends, existing differential trends in the asset risk weights could show up in the estimated effects of the levies. Le Leslé and Avramova (2012) find a marked country-specific element in the dynamics of risk weighted assets. By controlling for the differential trends, we can better identify the impact of the tax change on the taxed banks. Column (5) shows the full model. Again, the point estimate for the equity ratios (0.57) is in line with the previous specifications. The coefficient for interbank exposure is also qualitatively unchanged, although it decreases in magnitude (in absolute value) to −1.01. The estimate for the asset risk weights turns positive (0.84) and statistically significant at the 5% level. In Column (6) we use an alternative way to control for different time-varying unobservables at the local level. In this specification, we replace the country-specific trends with interactions between year and regional dummies, with the regions grouping countries with similar banking systems, as in Devereux et al. (2019). The size of the estimated coefficients in line with the previous estimates. Overall, because the definition of the regions might be deemed somewhat arbitrary, we consider the model in column (5) our preferred specification.

To evaluate the economic magnitudes of the regression results, we express the estimated coefficients as semi-elasticities, obtained as $(\partial y/\partial T)/y$. The numerator, $\partial y/\partial T$, is given by the coefficient estimate on the tax increase dummy from the regression model. For the denominator, the relevant outcome variables are set as equal to the corresponding sample means. The average value of the equity ratio in the years before the introduction of the liability taxes is around 10%. Using the coefficient in column 5 of Table 3, this translates into a semi-elasticity of around 6. The average value of the RWA density is 65%, leading to an estimated semi-elasticity of around 2, when the coefficient in the full specification is used (column 6 of Table 3). Finally, the average share of interbank deposits over total liabilities is 22%, which translates into a semi-elasticity of −5.

3.4.2. Does the size of the tax increase matter?

Liability taxes implemented in Europe have the same broad rationale, but are inherently heterogeneous in their design (see Annex 1). Both the definition of the taxable bases and the tax rates may differ markedly across countries. For instance, marginal tax rates vary from 0.020% to 0.4%. Against this background, banks may react differently depending on the size of the tax increase. A low tax rate has been advocated as non-distortive of cross-border flows for liability taxes introduced in the absence of global coordination (Shin, 2010). However, the actual burden may not be perceived as significant, particularly if compared to existing taxes, such as those on corporate profits. In evaluating the German levy, Buch et al. (2016) find differences in the banks' responses to the tax depending on the absolute size of the payment. In particular, banks that were more affected by the levy, i.e., facing a higher marginal tax rate, increased rates on newly received deposits more than those taxed less heavily.

To explore whether the magnitude of the tax burden matters, we exploit information on the rates of the taxes on borrowing to define two separate treatment variables. We partition the sample of banks depending on whether they faced low or high tax increases. As a threshold, we use the median value of the tax changes, and defined two dummies for exposure to levies for high, i.e. above the median value of the tax changes, or low tax changes, i.e. below the median. The results are shown in Table 4. Our three outcome variables are highly sensitive to large tax increases, but there is no statistically significant reaction to small tax changes. This confirms

Table 5
Anticipation and delayed effect of bank levies on capital structure and risk.

	(1)	(2)	(3)	(4)	(5)	(6)
	Equity ratio		Interbank exposure		Regulatory risk weights	
Tax increase at t + 2	−0.146		1.092		0.098	
	(1.530)		(5.323)		(8.083)	
Tax increase at t + 1	−0.112		1.151		1.088	
	(0.116)		(0.785)		(1.553)	
Tax increase at t	0.563***	0.567***	−0.934***	−1.028***	0.883**	0.843**
	(0.090)	(0.093)	(0.328)	(0.342)	(0.357)	(0.360)
Tax increase at t-1		−0.007		−0.347		0.317
		(0.059)		(0.446)		(0.430)
Tax increase at t-2		−0.067		−0.541**		−0.321
		(0.059)		(0.265)		(0.372)
Tax increase at t-3		−0.091*		−0.410		−0.307
		(0.047)		(0.278)		(0.424)
Bank controls	Yes	Yes	Yes	Yes	Yes	Yes
Country controls	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Regulatory controls	Yes	Yes	Yes	Yes	Yes	Yes
Capital-time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-time trends	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.369	0.369	0.381	0.381	0.283	0.283
Observations	7341	7341	7341	7341	7341	7341

The table presents results of the difference-in-difference estimations of the impact of taxes on bank capital structure and asset risk, including anticipatory and delayed effects of the tax increases. Dependent variables are, respectively: Equity ratio (columns 1 and 2), Interbank exposure, as a share of interbank deposits (columns 3 and 4); and Asset risk weights as a share of total assets columns 5 and 6. The model includes bank-level and country variables, including country-specific regulatory controls. In addition, they include time and country fixed effects, the interaction between year fixed effects with pre-treatment capitalisation quintiles, and country-specific time trends. Standard errors, robust for heteroscedasticity and clustered at the bank level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

the notion that the size of the tax increase affects banks' behavioural reactions to changes in the relative cost of their liabilities.

3.4.3. Dynamic effects and pre-trends

The first-difference model estimated in the previous section assumes that banks adjust their balance sheets as soon as the tax increases took place. This section explores the timing of the response in more depth. In general, tax changes are rarely surprise events. This is particularly true for taxes on bank borrowing, which were introduced in the context of a widespread policy debate on financial sector taxation. Anticipation effects may therefore be very important for these taxes. Additionally, not all bank balance sheet items are immediately adjustable. Hence, banks might take some time to reach their new desired balance sheet structure after the introduction of increased taxation on non-core liabilities. We check for anticipation effects and for slow adjustment or potential reversals of the reaction upon impact by adding lags and leads of the tax increase dummy in our preferred model specification. The results from the augmented model are shown in Table 5. The odd columns show the model augmented with the effect up to two years before the tax change.[10] For all three outcome variables—equity ratios, interbank exposure and asset risk weights—there is no evidence that taxed banks started adjusting their capital structure ahead of the tax change. This finding sheds light on the parallel trend assumption in the pre-treatment period, which is pivotal for the validity of the difference-in-differences approach.

The even columns in Table 5 show the results of the specification that allows for delayed impacts on the outcome variables, up to three years after the tax increase. We obtain mixed findings for the three outcome variables. Banks seem to correct the increase in equity downward as from the year immediately after the introduction of the levy. Overall, the combined effect in the three periods after the tax increase is still well below the positive effect upon impact, and only marginally significant. By contrast, the negative adjustment in the interbank exposure continues after the tax change. The coefficient upon impact therefore underestimates the overall impact of the increased cost of bank borrowing. Finally, there is no significant delayed impact of the levies on asset risk.

3.4.4. Impact of liability taxes: further results

In this section we examine other balance sheet channels of adjustment to liability taxes. We focus on the composition of liabilities and on asset liquidity. Next, we analyse the direct impact of bank levies on different measures of systemic risk.

3.4.4.1. Impact on additional balance sheet items. To examine the impact of bank levies on the composition of liabilities, we estimate Eq. (1) using four alternative variables: the leverage ratio, defined as total liabilities over total assets; the depository debt ratio; the non-depository debt ratio; and the regulatory ratio. The results are shown in Table 6. Taxes on borrowing reduce the leverage ratio

[10] Since almost all the tax levies were introduced in 2011, we cannot test for anticipatory effects for more than two years in our econometric setup.

Table 6
The effect of bank levies on additional balance items.

	(1)	(2)	(3)	(4)	(5)
	Leverage ratio	Depository debt ratio	Non-depository debt ratio	Regulatory ratio	Liquid assets to deposit ratio
Tax increase	−0.547***	0.218	−0.765	0.966***	2.326**
	(0.092)	(0.513)	(0.518)	(0.181)	(0.964)
Bank controls	Yes	Yes	Yes	Yes	Yes
Country controls	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Regulatory controls	Yes	Yes	Yes	Yes	Yes
Capital-time FE	Yes	Yes	Yes	Yes	Yes
Country-time trends	Yes	Yes	Yes	Yes	Yes
R-squared	0.366	0.297	0.256	0.254	0.442
Observations	7341	7341	7341	7341	7341

The table presents results of the difference-in-difference estimations of the impact of taxes on bank capital structure. Dependent variables are: the Leverage ratio, defined as the ratio between total liabilities and total assets (column 1); the Depository debt ratio, defined as the ratio between total deposits and total assets (column 2); the Non-depository debt ratio, defined as the ratio between total non-depository debt and total assets (column 3); the Regulatory ratio, defined as the ratio between equity capital and risk-weighted assets (column 4); liquid assets over total deposits (column 5). The model includes bank-level and country variables, including country-specific regulatory controls. In addition, they include time and country fixed effects, the interaction between year fixed effects with pre-treatment capitalisation quintiles, and country-specific time trends. Standard errors, robust for heteroscedasticity and clustered at the bank level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

(column (1)). Taken together with the main result on the equity ratio, this finding suggests that banks responded to the levies by changing the composition of their liabilities, rather than reducing the size of their balance sheet. Next, in column (2), we use the depository debt ratio, calculated as total deposits over total assets, as the dependent variable. The depository debt ratio increases as borrowing is taxed, but the effect is not statistically significant. This could be the combined effect of banks expanding customer deposits, which are tax-exempt when insured, and reducing interbank exposure, in line with our previous estimates. Column (3) reports the estimates for the non-depository debt ratio, which includes all debt items but deposits. As expected, the levies induce banks to reduce their non-deposit debt. However, the impact is not estimated with precision. Overall, this evidence suggests that the aggregate dynamics of bank liabilities in response to the levies hide important composition effects for different types of debt instruments.

Next, we examine the regulatory ratio, the ratio between equity capital and risk-weighted assets, as an alternative comprehensive measure of bank risk that is consistent with the capital requirements regulatory framework. We find that banks exposed to a tax on borrowing raise their regulatory ratio, holding more equity capital for a given level of asset risk. The increase is statistically significant at the 1% level.

Policies affecting bank capital can influence also liquidity creation by banks. From a theoretical perspective, opposing predictions emerge from the literature on how equity capital may affect banks' ability to create liquidity. According to the "financial fragility-crowding out" hypothesis, higher capital reduces liquidity creation. By contrast, the "risk absorption" hypothesis predicts that higher capital enhances the ability of banks to create liquidity (see the seminal contribution by Berger and Bouwman, 2009). Furthermore, on- and off-balance sheet liquidity creation can differ substantially (see ibidem). At the same time, the empirical evidence suggests that the impact strongly depends on the size and type of banks, the economic and financial cycle, the stage of development of the financial sector, etc. (see Casu et al., 2019, Distinguin et al., 2013, Horváth et al., 2014, Evans and Haq, 2021, among many others). Hence, a comprehensive evaluation of the impact of liability taxes on liquidity would need much deeper analysis and careful consideration – including for the construction of several measures of liquidity – that go beyond the scope of the current paper.

Nevertheless, as a first exploratory test, we consider the impact of the bank levies on the ratio between liquid assets and total deposit funding. This is the dependent variable in the econometric specification in column (5) of Table 6. The coefficient estimate for the bank levies dummy is positive and statistically significant (at 5% level), suggesting that banks increased liquid assets with respect to deposit funding in response to the levies. While this provides a first indication, drawing strong conclusions on the impact of bank levies on bank liquidity requires a more comprehensive assessment, as discussed above.

Table 7
The effect of bank levies on banks' contribution to systemic risk.

	(1)	(2)	(3)	(4)
	$SRISK^{med}$	$SRISK^{max}$	SES^{med}	SES^{max}
Tax increase $_t$	−0.491*	−1.457**	−0.827***	−0.911**
	(0.291)	(0.656)	(0.280)	(0.377)
Bank controls	Yes	Yes	Yes	Yes
Country controls	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Regulatory controls	Yes	Yes	Yes	Yes
Capital-time FE	Yes	Yes	Yes	Yes
Country-time trends	Yes	Yes	Yes	Yes
Observations	322	322	346	346
R-squared	0.537	0.491	0.544	0.499

The table presents results of the difference-in-difference estimations of the impact of bank liability taxes on two measures of systemic risk. Dependent variables are SRISK and SES. SRISK is the conditional capital shortfall measure of systemic risk, normalised by the bank's market capitalisation. It measures how much capital the bank would need in a crisis at each point in time to maintain a given capital ratio. The Systemic Expected Shortfall (SES) captures a bank's propensity to be undercapitalised when the system as a whole is undercapitalised. The superscript med and max indicate that the yearly systemic risk indicators have been obtained using the respective median and maximum values at quarterly frequency. The model includes bank-level and country variables, including country-specific regulatory controls. In addition, they include time fixed effects, the interaction between year fixed effects with pre-treatment capitalisation quintiles, and country-specific time trends. Standard errors, robust for heteroscedasticity and clustered at the bank level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3.4.4.2. Impact on systemic risk. In Section 4.1, the main predictions presented up until now will be used to evaluate the impact of bank levies on system-wide financial stability based on a microsimulation model of banking losses. Whereas this section, as a complement to that analysis, explores the impact of bank levies on several direct measures of systemic risk proposed recently in the literature. We re-estimate Eq. (1) using two alternative measures of banks' contribution to systemic risk as dependent variables. First, following Acharya et al. (2012) and Brownlees and Engle (2017), we use the conditional capital shortfall measure of Systemic Risk (SRISK), normalised by the bank's market capitalisation as in Berger et al. (2020). The conditional capital shortfall measures how much capital the bank would need in a crisis at each point in time to maintain a given capital ratio.[11] Our second measure is the Systemic Expected Shortfall (SES) proposed by Acharya et al. (2017), which captures a bank's propensity to be undercapitalised when the system as a whole is undercapitalised.[12] Both indicators are calculated using quarterly data, and further aggregated at yearly frequency.[13]

Table 7 shows the estimates of the impact of liability taxes on the SRISK and the SES indicators. For each measure of the contribution to systemic risk, the table includes two different values, obtained by annualising the quarterly systemic risk indicators using either the maximum or the median quarterly values. The corresponding annual indicators are shown by max and *med*.

The coefficient for the Tax $increase_t$ dummy is negative and statistically significant in all specifications, suggesting that liability taxes are associated with decreased contributions to systemic risk. Estimates suggest that a 1 percentage point increase in tax leads to a 1% reduction in the average taxed bank's contribution to systemic risk.

4. Liability taxes and the cost of banking crises

Our econometric results show that banks reacted to taxes on their debt in different way. Many banks increased capitalisation and changed the composition of their liabilities by reducing interbank exposure, which is consistent with the aim of the policy. However, an unintended consequence of the policy is that banks took more risk on the asset side. Whether and to what extent the taxes on borrowing translate into safer banks, and ultimately more stable banking systems, is ultimately an empirical question. We provide an answer to

[11] For a quarter indexed by t, the systemic risk indicator SRISK of a bank indexed by i is: $SRISK_{i,t} = k \cdot D_{i,t} + (1-k) \cdot (1 - LRMES_{i,t}) \cdot W_{i,t}$, where k is the prudential level of book equity relative to assets (set to 8% following Berger et al., 2020), $D_{i,t}$ denotes the book value of debt, $W_{i,t}$ is the market value of equity, and $LRMES_{i,t}$ the long-term marginal expected shortfall. Following Acharya et al. (2012) and Berger et al. (2020), the $LRMES_{i,t}$ is approximated by $1 - \exp.(-18 \cdot MES_{i,t})$, where $MES_{i,t}$ is the marginal expected shortfall. This is usually estimated by the negative of average daily bank returns over the 5% worst total market days in a quarter, i.e., whenever the total market daily returns are below (or equal to) their 5th percentile. We use the S&P 500 for total market returns. Non-synchronised market opening hours might create discrepancy between the largest market drops in the US and European markets, so to calculate the marginal expected shortfall we use the largest decrease during two consecutive days. All stock market data needed for the calculations of the indicators are drawn from Refinitiv Datastream. The normalised SRISK is given by $NSRISK_{i,t} = SRISK_{i,t} / W_{i,t}$. The dependent variable at yearly frequency was obtained by taking either the maximum or the median of quarterly $NSRISK_{i,t}$ values within a given year.

[12] Following Berger et al. (2020), the Systemic Expected Shortfall for bank i at time t ($SES_{i,t}$) is predicted by using Acharya et al. (2017) regression model: $SES_{i,t} = 0.02–0.15\ MES_{i,t-1}–0.04\ LVG_{i,t-1}$. Here, the $MES_{i,t}$ is measured as previously. Leverage ($LVG_{i,t}$) is approximated by: $LVG_{i,t} = 1 + (A_{i,t} - E_{i,t}) / W_{i,t}$, where $A_{i,t}$ and $E_{i,t}$ are the book value of assets and equity. The corresponding measure for the year used as the dependent variable is then obtained from the negative $SES_{i,t}$ values by taking the maximum or median of quarterly values within a given year. Larger values of the dependent variable correspond to a greater contribution of the bank to the systemic risk.

[13] The measures are calculated using market values, and the analysis in this section therefore covers only listed banks.

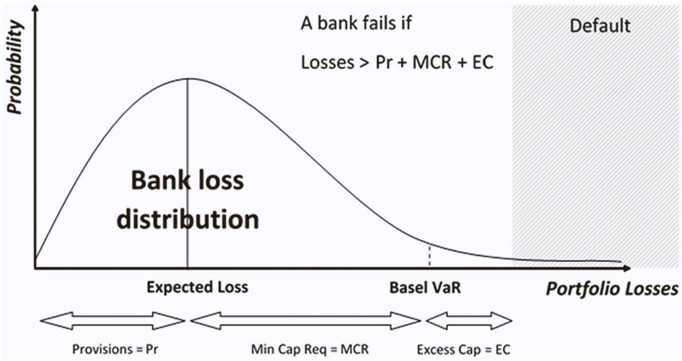

Fig. 4. Loss distribution and default of an individual bank.

that based on a microsimulation model for bank portfolio losses. The next section discusses the general modelling framework and the simulated scenarios, and the one after gives the results of the simulation exercise. More details on methodology and data are in Annex 3.

4.1. A microsimulation model for systemic banking losses

Our measure for systemic risk is the losses generated in the banking system in the event of a severe crisis. Following Benczur et al. (2017), we quantify losses using a microsimulation model, referred to as SYMBOL (SYstemic Model of Bank-Originated Losses). The model uses bank balance sheet data to simulate the cost of a financial crisis in terms of losses generated in the banking sector. The model starts by estimating an average implied default probability of bank obligors from risk-weighted assets, in a way that is fully consistent with the Basel framework. These estimates are then used to evaluate each individual bank's unexpected losses. In turn, these losses determine the bank's potential default, under-capitalisation and the need to use financial safety net tools under specific assumptions about the regulatory and resolution regime in place. The model output consists of an initial matrix of unexpected losses for bank *j* in country *i* (UL_{ji}), which are then transformed into losses in excess of capital (ExL_{ji}) plus recapitalisation needs, which we set equal to 10.5% of risk weighted assets.[14] Throughout the remainder of the paper, losses ($ExRL_{ji}$) refer to losses in excess of capital (ExL_{ji}) plus recapitalisation needs. These losses are absorbed by the bank's provisions (Pr), by the minimum capital requirement (MCR) and by excess of capital (EC) above the MCR, when available, in that order. A bank defaults when provisions and total capital (Pr + MCR + EC) are not sufficient to absorb portfolio losses. Fig. 4 provides a graphical representation of the distribution of losses for an individual bank. Adding all the losses of all distressed banks (i.e. both failed and undercapitalised banks) gives aggregate losses for the whole banking system.

In the second step, we introduce bank interconnectedness through the interbank market. Interbank exposure implies that bank default episodes will create portfolio losses in other intermediaries that are exposed to the distressed institutions. This spreads risk to the entire banking system, within and across national borders. Formally, allowing for contagion effects gives rise to an additional round of potential losses ($IBLosses_{ji}$) in the model setup. We assume that individual losses generated via the contagion mechanism would spread across intermediaries proportionally to the amount of interbank deposits held by each bank.[15] Overall losses are therefore computed as the sum of existing losses of all distressed banks ($ExRL_{ji}$) plus the potential losses ($IBLosses_{ji}$) generated by the contagion mechanism in the interbank market.

4.2. Simulation framework and scenarios

To gauge the impact of the bank levies, we compare the losses generated in two alternative scenarios: i) a baseline scenario with the taxes on bank borrowing in place; ii) a counterfactual scenario where we purged the data of the impact of the levies. For the baseline case, we use observed bank balance sheets in the year of the tax increase. Annex 3 provides a detailed characterisation of the simulation sample, focusing on the key determinants of losses in the model framework, notably equity capital, interbank exposure, and asset risk weights. We then build the counterfactual scenario, where the relevant balance sheet variables are adjusted in line with the behavioural reactions estimated in our difference-in-differences model. We use the model estimates in Table 3, column 5, as our benchmark. From the econometric model in Eq. (1), we obtain:

[14] We retain this percentile as our reference point in the EU27 + UK aggregate distribution. For each individual country *i,* we consider the losses' aggregate distribution and we re-order it following the sorted ordering of the EU27 + UK distribution. To smooth out uncertainty due to different realisation of losses, we use a Hodrick-Prescott (HP) filter and computed the 99.95th percentile on the smoothed HP trend.

[15] We assume that 40% of the interbank deposits held by banks in default would materialise as extra losses for other banks in the system. This 40% estimate is consistent with James (1991), who finds that the average loss of failed U.S. banks during the period 1985 to 1988 was about 30% plus direct costs associated with bank closures of 10% of the assets.

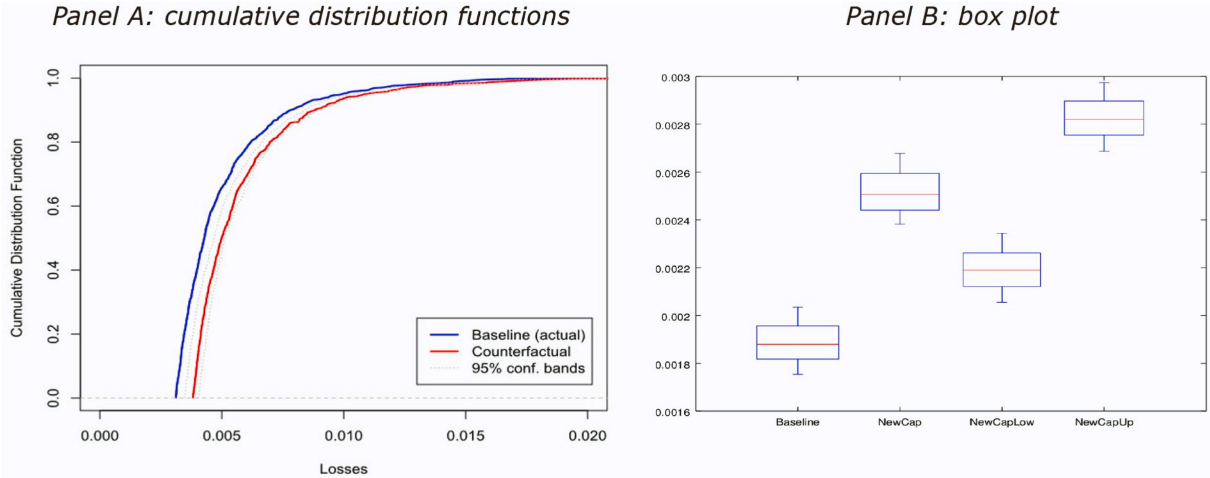

Fig. 5. Simulated bank losses: effect of changes in equity ratios.
Notes: the graph in Panel A plots the CDFs of simulated bank losses in the actual case with the bank levies in place (blue line) and the counterfactual scenario without levies, resulting in lower equity ratios (red line). The graph in Panel B display box and whisker plots of losses with the levies in place (baseline), and in the counterfactual scenarios without levies and, thus, lower equity ratios (corresponding to the central estimate, and its upper and lower bounds). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$\hat{y}_{ict} = y_{ict} - \Delta y = y_{ict} - \beta_0 T_{ict} \tag{2}$$

where $\hat{y}_{ict}$ is the counterfactual value of the outcome variable of interest, either the equity ratio, asset risk weights or interbank exposure. Equipped with the counterfactual values of the relevant outcome variables, we run the microsimulation model again to obtain losses in this alternative scenario. We disentangle the contribution of the different channels of adjustment by running the model for each of the channels individually. When all of them are considered together, we obtain the case without taxes on bank borrowing.

4.3. Results

This section shows and discusses the main results from the simulation exercise. It starts by focusing on the effects of balance sheet adjustment for equity and asset risk, without considering the interbank market and contagion effects. These issues are discussed later, because interbank linkages change the order of magnitude of simulated losses. The figures behind the plots are indicative of orders of magnitude, and depend on the sample used for the analysis. They should therefore be interpreted across scenarios, rather than in isolation.

4.3.1. Baseline results

Fig. 5 shows the impacts of an aggregate increase of capital on banking losses. Panel A plots the cumulative distribution functions (CDFs) of banking losses. The X-axis reports the aggregate losses as a fraction of total assets, and the Y-axis shows the associated probability of observing that level of losses. The solid blue line in the plot identifies losses in the baseline case, with taxes on borrowing. The solid red line shows losses in the counterfactual (short-term) scenario where equity capital has been adjusted to the lower level implied by the absence of liability taxes, using the results from the difference-in-differences model. To factor in the uncertainty of the econometric estimates, the dotted grey lines show the losses associated with changes in capital corresponding to the 95% confidence band around the central estimates for changes in equity. As expected, the distribution of losses in the counterfactual case without liability taxes stochastically dominates the distribution in the baseline case. This is because banks in the counterfactual scenario have lower capital than in the baseline. Expectedly, levies on borrowing incentivise banks to substitute their own funding for debt, and therefore lead to better capitalised banks. This implies an improved capacity to absorb losses, and ultimately results in a banking system that is safer and more resilient to adverse shocks. The box-plots of the distribution of losses in Panel B of Fig. 5 show how better capitalised banks in the baseline case with taxes on borrowing unambiguously lead to lower levels of losses.

Our econometric estimates suggest that the introduction of the levies determined a shift in riskiness from the liability side to the asset side of banks' balance sheets. Banks exploited the room created by more equity to increase the risk weight of their assets, which also provides higher returns. In the model framework, higher asset risk weights lead to larger excess losses. Next, we examine what happens in terms of banking losses when the estimated adjustment to asset risk weights takes place alongside the adjustment of capital. Fig. 6 plots the simulated losses. Panel A depicts the CDFs of aggregate losses in the baseline (blue line) and counterfactual when we consider both adjustments, in equity and asset risk weights, associated with the estimated average treatment effect of the taxes (red line). As before, we also include losses corresponding to the 95% confidence intervals for the estimated coefficients of adjustment for asset risk weights.

The stabilising effect of higher bank capitalisation under the liability taxes is not sufficient to counteract increased risk brought

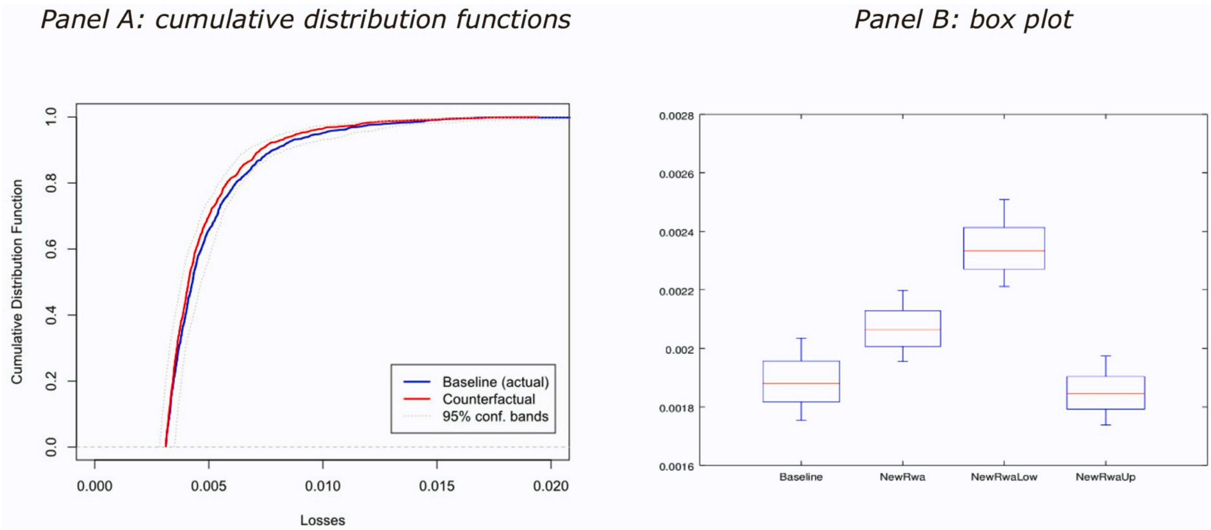

Fig. 6. Simulated bank losses: effect of changes in equity ratios and asset risk weights.
Notes: the graph in Panel A plots the CDFs of simulated bank losses in the actual case with the bank levies in place (blue line) and the counterfactual scenario without levies, resulting in lower equity ratios and higher risk weights (red line). The graph in Panel B display box and whisker plots of losses with the levies in place (baseline), and in the counterfactual scenarios without levies and, thus, lower equity ratios and higher risk weights (corresponding to the central estimate, and its upper and lower bounds). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

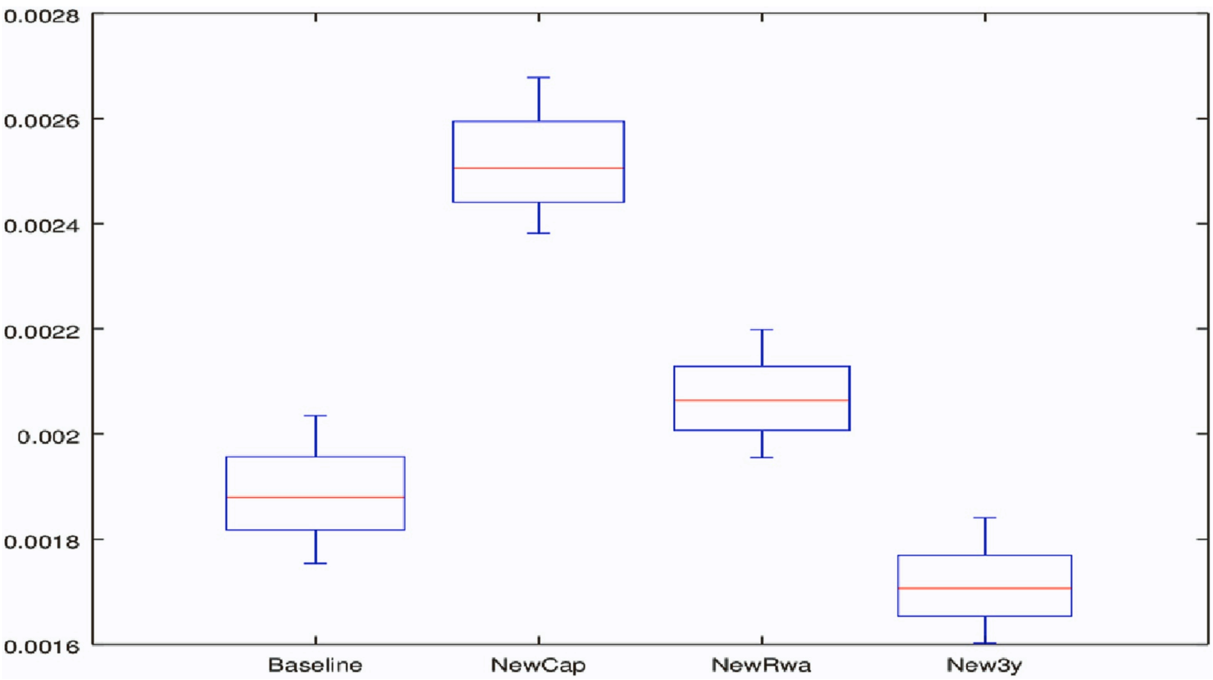

Fig. 7. Simulated bank losses: medium term effect of changes in equity ratios and asset risk weights.
Notes: the graph displays box and whisker plots of losses with the levies in place (baseline), and in the counterfactual scenarios without levies and, thus, with lower equity ratios alone (NewCap) and combined with higher asset risk weights, over the short term (NewRwa) and the medium term (New3y).

about by higher risk weights in the asset portfolio. However, the size of the adjustment in the latter variable is crucial. The levies on borrowing translate into higher losses than the baseline case when we consider the upper bound of the change in asset risk weights. This is apparent from the confidence intervals plot, where the CDF of losses in the baseline stochastically dominates the CDF of the

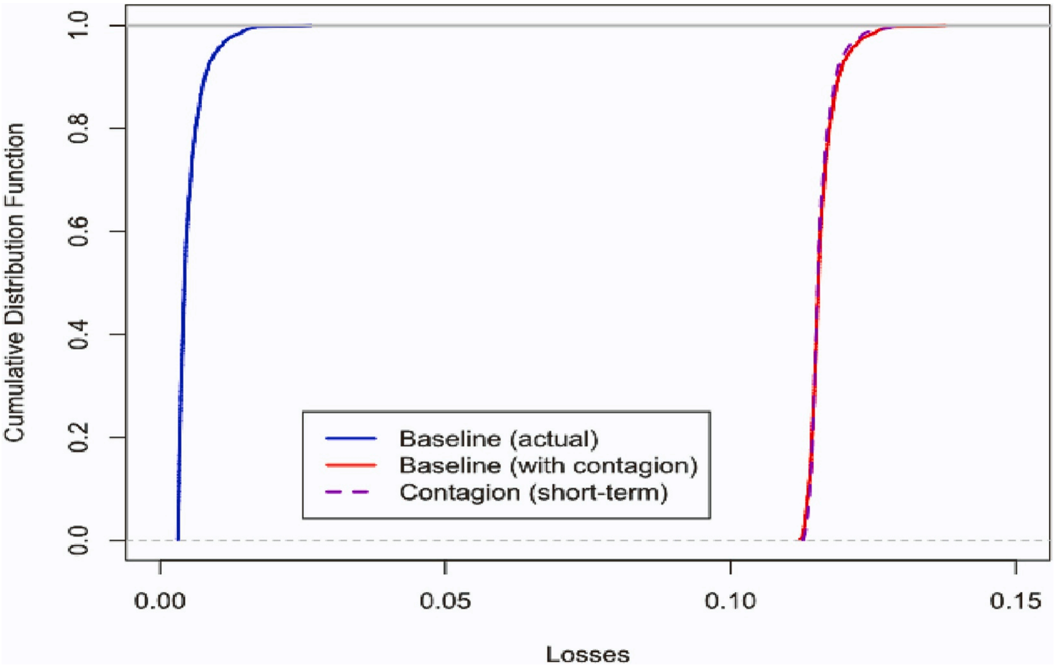

Fig. 8. Simulated bank losses: effect of changes in equity ratios and asset risk weights, with and without contagion.
Notes: the graph displays the CDFs of losses with the levies in place, both without (blue line) and with contagion (red line), and in the counterfactual scenarios without levies (dashed blue line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

counterfactual scenario. The box-plots of losses in Panel B of Fig. 6 show the pivotal role played by adjustment in the asset risk weights for systemic losses. Systematic losses are only unambiguously higher without liability taxes if asset risk does not significantly increase in response to the taxes on bank borrowing. This corresponds to the estimated lower bound of changes in asset risk weights (NewRwaLow in Panel B of Fig. 6).

4.3.2. Medium-term adjustment

The econometric results in Section 3.4.3 show the presence of lagged adjustment of bank balance sheets after increased taxation of borrowing. There is also evidence of partial reversals in the adjustment upon impact for capital ratios and asset risk weights. This section studies whether and to what extent this affects simulated losses and our previous conclusions on the impact of liability taxes on systemic risk. Fig. 7 shows the box-plots of the distribution of losses in the baseline case with taxes, and in three alternative counterfactual cases: short term adjustment in the capital ratio only; combined with assets risk weights; and with adjustment in both variables over the medium term (New3y). None of these cases includes the interbank market. As already discussed, losses are unambiguously higher in the counterfactual scenario where equity ratios are lower without liability taxes, but the results are less clear-cut once adjustment of asset risk is factored in. However, in the medium term, the overall adjustment in the equity ratio is more muted, and so is the change in asset risk weights. The counterfactual scenario without liability taxes therefore generally seems to result in lower losses in the medium term than the baseline case.

4.3.3. Contagion

So far, we have disregarded the contribution of banking losses spreading in the system due to contagion effects. As discussed above, introducing interbank linkages into the microsimulation model adds a further round of losses arising from bank interconnectedness. At the same time, at the margin, the introduction of the liability taxes brings about an adjustment in the composition of liabilities in favour of long-term and customer deposits. We therefore examine the effect of these on systemic losses. Fig. 8 shows the CDFs of losses as a fraction of total banking assets in two alternative cases, with and without additional portfolio losses generated in the interbank market. The solid lines depict the alternative baseline cases with liability taxes in place. The blue line shows the case without interbank linkages, which we use as a benchmark, and the red one the alternative case with the interbank market included. The cost of banking crises is much higher with the interbank market, precisely because of the additional losses originating due to contagion. By contrast, the contribution of marginal adjustments in the interbank exposure due to the liability taxes seems marginal, as shown by the dotted line.

5. Conclusions

In this paper, we analyse the effect of liability taxes on bank capital structure and risk. Using a difference-in-differences model, we document adjustment of bank balance sheets along three dimensions: equity ratios, interbank exposure, and risk weight of assets. We find that liability taxes have increased bank capitalisation and reduced interbank exposure but have led banks to shift risk onto the asset side of their portfolio. Accounting for dynamic adjustment effects shows a more muted overall adjustment in equity ratios and asset risk weights, but no reversals in the reduction in the share of interbank deposits. Using the same regression framework, we find that taxes on bank borrowing reduce banks' contributions to systemic risk.

We then assess the net effect on systemic risk using a microsimulation model for banking losses. We show that, by incentivising bank capitalisation, liability taxes have generally decreased the potential costs of systemic crises. However, when the increased risk on the asset side of bank balance sheets is large, higher losses may materialise with the levies on borrowing in place than in the counterfactual case without levies. Contagion effects on the interbank markets do not qualitatively change these findings. Liability taxes reduce loss-cascading effects on the interbank market through a decrease in interbank deposits, but the increased risk on the asset side is still predominant. Levies are therefore generally beneficial to financial stability, but there are cases where they might have unintended effects of increasing losses in the event of a severe crisis if they trigger a substantial adjustment in asset risk weights. From a policy perspective, the issue related to capital substitution towards riskier assets is very relevant and our findings suggest that it is important to calibrate carefully when designing bank levies. Adjustments on the funding side without adequate correction of the risk of assets might partially reduce the benefit of bank liability taxes.

Data availability

The authors do not have permission to share data.

Acknowledgements

We are grateful to the Editor Scott Baker, and two anonymous referees for very constructive comments. We also thank Alexander Borisov, George Pennacchi, Zhenyu Wang, Alberto Zazzaro, Giacomo Ricotti, Tommaso Oliviero, and participants at the 7th MoFiR Workshop on Banking, the Bank of Italy 20th Workshop on Public Finance, and at various seminars for useful suggestions. The work was carried out when all authors where at the European Commission - Joint Research Centre. The opinions and views expressed are those of the authors only and should not be considered as official positions of the European Commission or the Single Resolution Board.

Appendix A. Annexes

Annex 1
Liability taxes in Europe.

	Tax base	Rate structure	Entry into force
Levies on bank borrowing:			
Austria*	total liabilities net of equity and insured deposits	0.000% up to €1 billion 0.055% up to €20 billion 0.085% above €20 billion	2011
Belgium	total liabilities net of equity and insured deposits	0.035%	2012
Cyprus	total liabilities net of equity	0.090%	2011
Germany	total liabilities net of equity and insured deposits	0.000% up to €300 million 0.020% up to €10 billion 0.030% up to €100 billion 0.040% up to €200 billion 0.050% up to €300 billion 0.060% above €300 billion	2011
Latvia	total liabilities net of equity and insured deposits	0.036%	2011
Portugal	total liabilities net of equity and subordinated debt	0.050%	2011
Romania	total liabilities net of equity and insured deposits	0.100%	2011
Slovakia	total liabilities net of equity and insured deposits	0.400%	2012
Sweden	total liabilities net of equity and insured deposits	0.036%	2009
Netherlands	total liabilities net of equity and insured deposits	0.000% up to €20 billion 0,044% above €20 billion (half rate for long-term funding)	2012
United Kingdom	total liabilities net of equity and insured deposits but netting of gross assets and liabilities against the same counterpart and deduction for liquid assets	0.000% up to £20 billion 0.088% above £20 billion (half rate for long-term funding)	2011

Notes: * Levy payments in 2011–2013 were a function of the balance sheet in 2010; **Exceptions apply depending on the stock and growth of lending to non-banks.

Annex 2
List of variables.

Variable	Definition	Source
Equity ratio	Ratio of equity to total assets.	Bankscope
Interbank exposure	Ratio between deposits from other banks and total liabilities.	Bankscope
Asset risk weights	Ratio of risk-weighted assets (RWA) to total assets.	Elaborations on Bankscope data.
Total Assets (Log)	The natural logarithm of total asset of a bank. It is calculated as [Log (Total assets)].	Bankscope
Leverage ratio	Ratio of total liabilities to total assets.	Bankscope
Depository debt ratio	Ratio between total deposits and total assets.	Bankscope
Non-depository debt ratio	Ratio between total non-depository debt and total assets.	Bankscope
Regulatory ratio	Ratio between regulatory capital and risk-weighted assets.	Bankscope
Liquid asset over Total Deposit Funding	Ratio between liquid assets over total deposit funding.	Bankscope
ROA	The Return on Assets is an indicator used to evaluate the profitability of the assets of a bank and it is used as an appraisal for determining their performance. ROA is computed as Net Income divided by Total Assets. We take the lagged value of total assets.	Bankscope
GDP_growth	Annual percentage growth rate of GDP at market prices based on constant local currency.	World Bank Open Data downloaded in April 2016.
Central Bank Interest Rate	Central bank reference rate	ECB
Tax increase (0/1)	Dummy variable that identifies the average impact on taxed banks in countries-years that introduced levy taxation. It takes the value of one for taxed banks and zero otherwise.	Devereux et al. (2019) and authors elaborations
EBA-ECB stress test, comprehensive assessment and capital exercise recommendation.	Dummy variable that identifies the average impact on banks in years that have been exposed to EBA-ECB stress tests, comprehensive assessment, and capital exercise. It takes the value of one for banks underwent EBA-ECB stress tests, comprehensive assessment and capital exercise and zero otherwise.	Authors' elaborations on EBA report
State aid recapitalisation	The overall amounts of capital for banks' recapitalisation, including liquidation aid, provided in a reporting year by a European Country.	European Commission Scoreboard 2015 State Aid
State aid impair assets measures	State aid impaired assets measures show the amounts of aid implemented in a reporting country-year, calculated as the transfer value of assets minus their market value. The unwinding of impaired asset measures is not taken into account.	European Commission Scoreboard 2015 State Aid
State aid liabilities guarantees	State aid liabilities guarantees are the volume of guarantees on liabilities in a reporting country-year calculated as the outstanding amounts as of 31 December of that year.	European Commission Scoreboard 2015 State Aid
State aid other liquid measures	State aid other liquid measures represent the volumes of liquidity measures in a reporting country-year calculated as the outstanding amounts as of 31 December of that year.	European Commission Scoreboard 2015 State Aid
SRISK	The conditional capital shortfall measure of systemic risk, normalised by the bank's market capitalisation, measures how much capital the bank would need in a crisis at each point in time to maintain a given capital ratio.	Authors' calculations on Refinitiv Datastream data
SES	The Systemic Expected Shortfall measures a bank's propensity to be undercapitalised when the system as a whole is undercapitalised.	Authors' calculations on Refinitiv Datastream data

Annex 3. Data for the SYMBOL model

This Annex describes the data used for the simulations. We only consider banks subject to the liability taxes.

Table A-1
Descriptive statistics for the simulation sample.

Country	Banks	Total Assets (TA)	Capital	Risk-Weighted Assets (RWA)	Interbank deposits	Sample ratio (% TA)	TA/GDP (%)
AT	24	148	8.26	59	47	17.11	44.95
BE	18	594	27.43	192	56	69.56	147.81
CY	2	4	0.51	3	1	4.66	23.12
DE	152	3647	152.91	1294	756	48.30	125.63
LV	13	23	2.53	12	2	86.52	96.66
NL	2	749	43.71	236	19	31.70	115.14
PT	11	117	6.47	65	14	26.70	67.01
RO	9	37	2.88	22	7	44.93	24.50
SE	61	629	34.46	162	61	55.47	146.63
SK	6	16	1.42	9	1	29.72	21.83
UK	8	5055	274.98	1953	212	126.12	226.81
Total	337	18,933	875	6350	1551		195.93

Notes: Data are unconsolidated with the exception of France, UK and Netherland where levy applies at banking group level. Total assets, capital, RWA, and loans are expressed in billion euros. Shares of TA over GDP adjusted for sample representativeness.

Table A-1 provides some descriptive statistics for the simulation sample. Overall, the microsimulation sample includes 337 banks. The coverage ratio is quite heterogeneous across countries. Due to the limited number of banks, for some countries (e.g., Cyprus, Netherlands) results might be prone to numerical uncertainty. For the purpose of the simulation exercise, capital and risk-weighted assets have been adjusted by using the correction coefficients provided by the Basel III monitoring exercise (Quantitative Impact Study, QIS) run by the European Banking Authority EBA.[16] These adjustments aim to better represent the level and quality of capital and the proper calculation of risk. Hence, they would decrease capital and increase RWA. Since the correction coefficients yearly change, we adopt those reported for the year of simulation (Table A-2). The table indicates that the size of the adjustment increases as the adjustment factors diverge from 1, which represents the benchmark of no adjustment.

Table A-2
QIS adjustment factors for 2014.

	RWA				Capital			
2014	G-SIIs	G1	Medium G2	Small G2	G-SIIs	G1	Medium G2	Small G2
	1	1.007	1.006	1	0.87	0.9	0.93	0.92

Notes: G-SIIs are Global Systemically Important Institutions, as identified by the European Banking Authority. G1 banks are banks with Tier 1 capital in excess of € 3 billion and that are internationally active. All other banks are categorised as G2 banks. EBA has classified G2 banks into sub-samples: large, which have Tier 1 capital in excess of € 3 billion; medium-sized, with Tier 1 capital below or equal to € 3 billion and above € 1.5 billion; and small, which have Tier 1 capital below or equal to € 1.5 billion.

The SYMBOL model simulates losses on the basis of the probability of default faced by the single banks, as implied by their risk-weighted assets (RWA). Relevant losses are those not covered by banks' capital. Therefore, RWA and capital are the key drivers of the bank-specific losses, further aggregated into systemic losses at the country and EU over the sample of banks. Interbank loans and deposits are the relevant variables for characterising the contagion mechanism. Each bank's connections to the rest of the banking system determine how widespread the contagion is and the losses involved. On average, the banks in our sample hold capital for as much as 6% of their total assets, with a minimum of 5% in Germany and a maximum of 12% in Cyprus. The RWA density is on average 33.3% in the sample. As a mirror image of high capital levels, extreme values are reached in the same countries. In other words, high levels of capital are associated with higher levels of risk on the asset side of banks' balance sheet. This is not surprising if banks are compensating the higher funding costs of equity capital by seeking correspondingly higher returns from riskier assets. The countries, where levy applies, with the higher RWA are Cyprus, Romania, Slovakia, Portugal and Slovenia, respectively.

Contagion is modelled through the interbank market. The interbank network is constructed using two layers:

1. We select banks in the top 10th percentile in terms of assets with at least one bank in each country.
2. Within country: linking the largest banks and small banks, cutting the links among large banks and among small banks.
3. Across countries: each largest bank in a country is linked to the largest bank in other countries if there exists a cross country exposure between the two given countries as reported by BIS.

To simulate contagion, one needs additional assumptions on the structure of the interbank market. In particular, in line with Roukny et al. (2014) and Bargigli et al. (2015), we assume that (i) banks lend to each other, independently of size, within each country, and (ii) large banks lend to large banks between countries. A large bank is a bank which has higher total assets than 90% of the sample. In case there is no bank that satisfies these criteria in a given country, we assume that the largest bank in that country is a large bank.

To identify whether a pair of countries are actually linked by bilateral cross-country exposure in the interbank market, we use aggregate information on exposures of European countries provided by the BIS Locational Banking Statistic database. The matrix is reported in Fig. A-1.

[16] The European Banking Authority (EBA) has been monitoring and assessing the impact of the Basel III rules on a sample of EU banks since June 2011. This exercise is performed with biannual reporting dates (June and December). In this specific case we refer to the EBA, Basel III monitoring exercise run on 2014. The relevant set of regulatory requirements in the EU comprises the Capital Requirements Directive (CRD IV) and the Capital Requirements Regulation (CRR), referred to hereafter CRD IV–CRR, excess of EUR 3 billion; medium-sized, with Tier 1 capital below or equal to EUR 3 billion and above EUR 1.5 billion; and small, which have Tier 1 capital below or equal to EUR 1.5 billion.

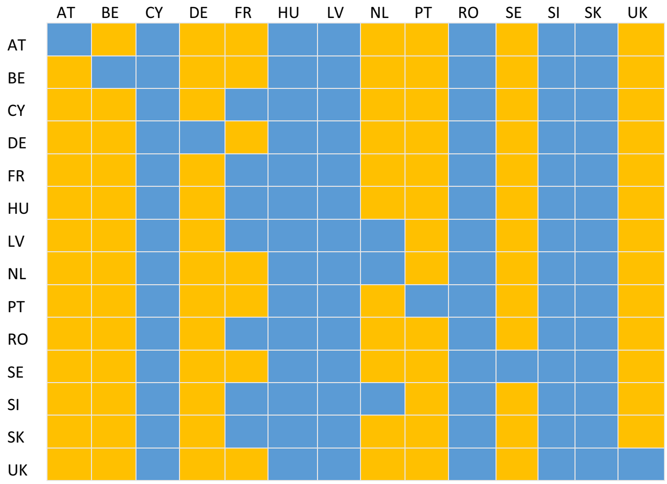

Fig. A-1. Adjacency matrix for BIS data on cross-border exposures.
Blue cells identify inactive nodes, while orange cells identify the active ones. Nodes on the secondary diagonal are inactive by construction since they identify exposure of a country towards itself.

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