Online Appendix for "The Economics of Supranational Bank Supervision"

Appendix A: Background on cooperation agreements

Supervisory authorities recognized in the Basel Concordat (BIS, 1975, 1983) the importance of good work relationships with their counterparts where a cross-country institution exists. Over the years, the Basel Committee has produced several documents that define good practice principles and essential elements of successful cooperation between banking supervisors. At the core of these principles is the establishment of regular flows of information and mechanisms for establishing trust between regulators regarding the confidentiality of the information shared. In this context, supervisors have entered into various types of arrangements to comply with these recommendations, including the exchange of letters, Memorandum of Understandings (MoU), and College of Supervisors (CoS). These arrangements have been signed bilaterally by a country-pair or multilaterally by a group of countries. Furthermore, while the Basel Committee guidelines are not mandatory, countries have largely followed the essential elements defined in these documents when designing the arrangements for the various forms of cooperation.

A Memorandum of Understanding in this context is a declaration of intent of cross-border cooperation between the parties regarding the supervision of international banks. They introduce the appropriate procedures and principles that facilitate such cooperation. These agreements are not legally binding and usually define supervision guidelines during normal times. The Committee has defined the essential elements of these agreements (BIS (2001)): (1) the establishment of information sharing between supervisors to facilitate effective consolidated supervision of multinational financial institutions, (2) mutual assistance in carrying out on-site inspection of these establishments, (3) the recognition of the importance of mutual trust and protection of the information shared, and (4) the ongoing coordination between the parties.

One step further in cooperation are the Colleges of Supervisors. These colleges are multilateral working groups of supervisors that collaborate with the purpose of enhancing effective consolidated supervision of a given multinational banking group. The principles included in a CoS are the same ones included in an MoU. However, the CoS should establish an additional step towards cooperation in crisis management (see, e.g., BIS (2010a)). Even though they are not decision-making bodies, they should operate as conduits of information for contingency planning in crisis

management meetings.

Cross-border supervision in crisis periods is further addressed in MoUs on crisis management. These MoUs are intended to provide authorities with additional guidelines during these periods. For instance, the establishment of the exchange of additional information, not shared during normal times, which is necessary during crisis periods. This information could involve, for instance, cross-sectoral flows of information, between the central bank and the supervisor. These agreements also provide effective sets of bank resolution tools, such as the promotion of ex-ante burden sharing (BIS, 2010b).

Countries reach the highest level of cooperation when forming a banking union. This form of cooperation transfers banks' supervision from the national level to a single supranational level authority.

Appendix B: Examples cooperation agreements

The following links provide examples of the different cooperation agreements:

Example MoU for information sharing and on-site inspection

Example College of Supervisors

Example MoU on crisis management and resolution

Appendix C: Distribution of Cooperation Agreements

Table A.1: Distribution of cooperation agreements

Country	Cooperation	Country	Cooperation
Algeria	0	Latvia	0.16
Angola	0.04	Liberia	0.04
Argentina	0.1	Lithuania	0.13
Australia	0.09	Luxembourg	0.33
Austria	0.23	Malawi	0.02
Barbados	0.02	Mali	0.12
Belgium	0.29	Malta	0.14
Benin	0.12	Mauritania	0
Bolivia	0.02	Mauritius	0.11
Botswana	0.01	Mexico	0.16
Brazil	0.05	Mozambique	0.02
Bulgaria	0.2	Namibia	0.04
Burkina Faso	0.12	Netherlands	0.3
Burundi	0.04	New Zealand	0.02
Cambodia	0.01	Nicaragua	0.1
Cameroon	0.13	Niger	0.12
Canada	0.11	Nigeria	0.17
Chile	0.04	Norway	0.24
Colombia	0.12	Panama	0.21
Congo, Dem. Rep.	0.05	Paraguay	0.02
Costa Rica	0.08	Peru	0.09
Cote D'Ivoire	0.11	Poland	0.25
Croatia	0.05	Portugal	0.07
Cyprus	0.21	Romania	0.2
Czech Republic	0.21	Rwanda	0.05
Denmark	0.22	Senegal	0.12
Dominican Republic	0.1	Sierra Leone	0.04
Ecuador	0.02	Slovak Republic	0.25
Egypt	0	Slovenia	0.18
El Salvador	0.12	South Africa	0.2
Estonia	0.16	Spain	0.26
Ethiopia	0	Sudan	0.02
Finland	0.16	Swaziland	0.01
France	0.38	Sweden	0.17
Gambia	0.04	Switzerland	0.18
Germany	0.4	Tanzania	0.09
Ghana	0.05	Togo	0.12
Greece	0.17	Trinidad and Tobago	0.02
Guatemala	0.11	Tunisia	0
Guinea-Bissau	0.12	Uganda	0.05
Honduras	0.08	United Kingdom	0.37
Hungary	0.18	United States	0.24
Iceland	0.1	Uruguay	0.09
Ireland	0.28	Venezuela	0.04
Italy	0.29	Zambia	0.05
Jamaica	0.02	Zimbabwe	0.11
Kenya	0.12		

This table shows for each country the fraction of agreements signed by 2013 relative to the number of all possible agreements.

Appendix D: Variable Definitions

Variable	Definitions	Source
Panel A: Effectiveness of regulation		
Bank risk		
Log(Z-Score)$_b$	Is a bank's natural logarithm of Z-score calculated as the ROA plus equity (over assets) divided by the three-year standard deviation of ROA from years $t-2$ to t.	Authors' calculation using Bankscope data.
MES$_b$	Corresponds to the average daily stock return of the bank on days where the country's local banking sector index (MSCI banking sector index) experiences one of its 5% lowest returns.	Authors' calculations based on Datastream share price data.
NPL/TL$_b$	Is the ratio of a bank's non-performing loans over total loans.	Authors' calculation using Bankscope data.
Loan growth$_b$	Corresponds to the annual growth lending rate.	Authors' calculation using Bankscope data.
Bank-specific cooperation		
Cooperation$_b$	Is the share of host supervisors (i.e., supervisors of the parent bank's subsidiaries) with whom the home (parent-bank) supervisor has a cooperation agreement. To calculate the share we weigh by the importance of each subsidiary, measured as the subsidiary's share in the parent bank's total foreign assets.	Authors' calculations based on Bankscope data and cooperation data from Central Banks' and Supervisory authorities' websites and other sources.
Subsidiary structure		
Host countries$_b$	Is a bank's number of host countries.	Authors' calculations based on Claessens and Van Horen (2014) and hand-collected information on ownership from annual reports, banks' and regulators' websites, and newspaper articles.
Foreign subsidiaries$_b$	Is a bank's number of foreign subsidiaries.	Authors' calculations based on Claessens and Van Horen (2014) and hand-collected information on ownership from annual reports, banks' and regulators' websites, and newspaper articles.
Bank controls		
Foreign TA/TA$_b$	Ratio of the bank's foreign to total assets.	Authors' calculation using Bankscope data.
Log(assets)$_b$	Logarithm of total assets in US dollars.	Authors' calculation using Bankscope data.
Liabilities/TA$_b$	Total liabilities over total assets.	Authors' calculation using Bankscope data.
Loss prov./TL$_b$	Loan-loss provisions divided by total loans.	Authors' calculation using Bankscope data.
Non-interest income/Income$_b$	Total non-interest income over total income.	Authors' calculation using Bankscope data.
Liquid/TA$_b$	Liquid assets over total assets.	Authors' calculation using Bankscope data.
Income/cost$_b$	Ratio of income over costs.	Authors' calculation using Bankscope data.
Capital ratio$_b$	Tier 1 and Tier 2 capital as a percentage of risk-weighted assets.	Authors' calculation using Bankscope data.
Country controls		
Log(GDP per cap)$_j$	Logarithm of GDP per capita.	World Bank data.
Vol(GDPgrowth)$_j$	Standard deviation of GDP growth measured over a five-year rolling window.	World Bank data.
Trade/GDP$_j$	Imports plus exports over GDP.	World Bank data.
Regulatory variables		
Supervisory stringency$_j$	Index that ranges between 0 and 7 that indicates overall capital stringency. Higher values indicate greater stringency.	Wold Bank survey on bank regulation (Barth, Caprio and Levine, 1999, 2003, 2007 and 2011).
External audit$_j$	Dummy equal to one if banks' financial statements have to be audited by a licensed or certified external audit.	Wold Bank survey on bank regulation (Barth, Caprio and Levine, 1999, 2003, 2007 and 2011).
Foreign entry$_j$	Index that ranges between 0 and 4 that indicates whether there are limits to foreign entities from entering. Higher values indicate more freedom.	Wold Bank survey on bank regulation (Barth, Caprio and Levine, 1999, 2003, 2007 and 2011).
Instrument		
Affinity$_i j$	Signorino and Ritter (1999) measure of political affinity defined as the similarity of voting patterns in the U.N. General Assembly.	Voeten (2013)

Variable definitions (cont.)

Variable	Definitions	Source
Panel B: Cooperation determinants		
Cooperation		
Cooperation_{ij}	Dummy variable equal to one if country i and country j have signed a Memorandum of Understanding or College of Supervisors agreement for cooperation in cross-border supervision or if they have a supranational supervisor.	Central Banks' and Supervisory authorities' websites and other sources.
$\text{Cooperation intensity}_{ij}$	Ordinal variable that ranges from zero to four if (i) the countries do not cooperate, (ii) have a Memorandum of Understanding for information sharing and on-site inspection, (iii) have a College of Supervisors, (iv) have a Memorandum of Understanding on crisis management and resolution and (v) have a supranational supervisor.	Central Banks' and Supervisory authorities' websites and other sources.
Externality		
Externality_{ij}	Corresponds to the average of a set of variables' differences between each country-pair observation and the minimum of that variable normalized by the difference between the maximum and the minimum of the variable.	Authors' calculations.
$\text{Avg. foreign share}_{ij}$	Corresponds to the average of the share of assets from country j operating in country i and vice versa.	Authors' calculation using Bankscope data and Claessens and Van Horen (2014).
Correlation_{ij}	Corresponds to average correlation between country i and j stock market index when each country's index experiences the 5% lowest returns. We use the Datastream index whenever available, other the MSCI index.	Datastream and MSCI market index.
Currency_{ij}	Dummy variable equal to one if country i and country j have the same currency, their currencies are fixed with respect to the other or their currencies are fixed with respect to a third common currency.	IMF.
G-SIB_{ij}	Dummy variable that equals one if there exists at least one Global Systemically Important Bank that has operations in both countries i and j.	Financial Stability Board (2013).
Heterogeneity		
$\text{Heterogeneity}_{ij}$	Corresponds to the average of a set of variables' absolute values of the differences between both countries' observations normalized by the difference between the maximum and the minimum of the variable.	Authors' calculations.
$\Delta\text{Preferences}_{ij}$	Negative of Signorino and Ritter (1999) measure of political affinity defined as the similarity of voting patterns in the U.N. General Assembly, normalized to be between zero and one.	Voeten (2013)
$\Delta\text{Foreign share}_{ij}$	Absolute value of the average of the difference between the banks' foreign assets of one country in the other over the total assets of the other country banking system and over the total assets of the country banking system, and vice versa; normalized by the difference between the maximum and the minimum of this variable.	Authors' calculation using Bankscope data and Claessens and Van Horen (2014).
$\Delta\text{Legal Origin}_{ij}$	Dummy variable equal to zero if both countries have the same legal origin (English, French, German, Socialist or Scandinavian), and equal to one otherwise.	LaPorta, et al. (2008).
$\Delta\text{Latitude}_{ij}$	Absolute value of the difference between both countries' latitude coordinates of the capital, normalized by the difference between the maximum and the minimum of this variable.	Nationmaster.
$\Delta\text{Longitude}_{ij}$	Absolute value of the difference between both countries' longitude coordinates of the capital, normalized by the difference between the maximum and the minimum of this variable.	Nationmaster.
$\Delta\text{Language}_{ij}$	Dummy variable equal to zero if both countries speak the same language, and equal to one otherwise.	CIA World Factbook.
$\Delta\text{Debt/GDP}_{ij}$	Absolute value of the difference between both countries' government debt as a share of GDP, normalized by the difference between the maximum and the minimum of this variable.	IMF.
$\Delta\text{GDP per capita}_{ij}$	Absolute value of the difference between both countries' gross domestic product divided by midyear population, normalized by the difference between the maximum and the minimum of this variable.	World Bank.
Other control variables		
Trade_{ij}	Corresponds to the sum of exports and imports between the two countries over the sum of both countries' GDP.	Barbieri and Omar (2012).
PTA_{ij}	Dummy variable equal to one if a preferential trade agreement exists between the two countries.	World Bank.
Internet use_{ij}	Corresponds to the sum of both countries' individual use of the internet as a percentage of each country's population.	World Bank.
Crisis	Dummy variable equal to one starting in 2008.	
Common share_{ij}	Corresponds to the number of third countries with which country i and country j have a cooperation arrangement over the total possible number of joint countries that the two can cooperate with.	Authors' calculations based on collected data on cooperation.

Appendix E: Robustness

The results in Table A.2 confirm our main findings using various robustness tests. To start with, we run several tests to address concerns about the endogeneity of the bank-level cooperation index. As previously discussed, (within-bank) variation in the cooperation index arises either when the parent country forms new cooperation agreements or when the bank's subsidiary structure changes. First, changes in supervisory cooperation itself may be endogenous due to omitted variables or reverse causality; the benefits from cooperation increase with cross-border linkages, which may also affect bank's stability, or cooperation arises as a response to deteriorated bank health. Second, the subsidiary structure may be dependent on cooperation; for example, cooperation may lead to retrenchment and a reduction in assets in subsidiary countries with whom the home country cooperates (as suggested by the theory in Calzolari, Colliard, Lóránth (2018)).

We first note that our baseline specification includes bank-level fixed effects, so any time-invariant differences between cooperating banks and non-cooperating banks are captured by these effects. However, as mentioned, differences in bank-level trends before cooperation could explain our findings. Thus, we explicitly examine these differences in risk trends for banks that have signed cooperation agreements with their subsidiaries' host countries (treated banks) and banks that have not signed any agreement (control banks). We graphically examine the risk evolution for both groups of banks. For this, we average the banks' Z-scores within group-time. Specifically, a bank is defined as treated if the yearly change in the bank's weighted cooperation indicator is larger than the 75th percentile of this change in the sample. Banks in countries that did not sign any agreement with their subsidiaries' host countries during our sample period form the control group. Treated banks are matched to control banks in the same country and year. Figure A.1 shows the evolution of the Z-scores for both groups of banks. $t = 0$ in this graph indicates the time when a bank increases cooperation according to the treatment definition. The figure shows no significant upward or downward trend in the difference between average Z-scores for control or treated banks in the years before the agreements are signed. This evidence, therefore, supports the assumption that there are no diverging trends in risk levels already prior to cooperation. Furthermore, this figure also shows an increase in the

Z-score of treated banks right after the increase in cooperation, while control banks experience a reduction in risk between t+1 and t+3. This evidence suggests that banks that increased cooperation with their host countries indeed increase their stability, and the difference in risk between control and treated banks fades away over time after cooperation.

Figure A.1 thus suggests that banks' risk trends do not determine cooperation, and the effect on bank risk is observed only after cooperation increases. However, we do observe that control banks have, on average, a higher Z-score compared to treated banks before cooperation - something that our model accounts for by bank fixed effects. Nevertheless, to further allay reverse causality concerns related to the signing of cooperation agreements, we first re-estimate our baseline model, but now lagging the cooperation indicator by one year. The first column in Table A.2 shows that our results remain unchanged when considering the lagged cooperation indicator.

As previously discussed, most of the within-bank variation in the bank-level cooperation indicator comes from the signing of cooperation agreements rather than changes in the subsidiary structure. However, to reduce concerns with respect to biases arising from the endogenous nature of this structure, in a second test we re-estimate our model in column (1) and calculate the lagged cooperation indicator using the subsidiary structure at the beginning of the sample period (in case a subsidiary was formed during the sample period, this implies that the subsidiary receives a weight of zero, thus effectively dropping it from the analysis). By using only subsidiary information at the beginning of the sample period, we exclude any variations in the subsidiary structure that may occur due to changes in cooperation during the sample period (and our bank-fixed effects absorb time-invariant differences in the subsidiary structure). The results of this model are shown in column (2). As expected, results remain unchanged.

Third, we employ an instrumental variable approach to address remaining concerns about the endogeneity of the bank-level cooperation index, for instance, due to omitted variables. We construct an instrumental variable based on two components. First, we estimate cooperation propensities at the *country-pair* level. Specifically, we exploit the fact that higher political affinity is related to lower country pair heterogeneity. We make use of an affinity measure widely used in the political

science literature (e.g., Signorino and Ritter (1999)), where affinity is defined as the similarity in voting patterns in the U.N. General Assembly. For this, we obtain data on countries' roll call votes in the U.N. General Assembly during our sample period from Voeten (2013). For country pair (i, j) in year t, affinity S is measured as follows

$$S_{i,j,t} = 1 - \frac{\sum_{r=1}^{R} \left| V_r^i - V_r^j \right|}{R}, \tag{1}$$

where R is the number of resolutions and V_r^i and V_r^j, are the votes of each country in each resolution in that year. Following the literature, we code $V = 1$ if the country voted "Yes", $V = 0$ if the country "Abstain", and $V = -1$ if the country voted "No". The measure varies between -1 and 1, where higher values indicate greater affinity.

This approach has been applied in previous literature to measure similarity in preferences among states (e.g. Andersen, Harr, and Tarp, (2006) and Garmaise and Natividad, (2013)). Similarity in preferences (at the country-pair level in our context) is expected to increase the probability of supervisory cooperation.[1] As (individual) banks are unlikely to influence both countries' diplomatic decisions, reverse causality should not be a concern in this context. We nevertheless take the one-year lag of the affinity variable in our estimation to account for this concern. Further, since affinity is a bilateral measure, it is unlikely that country-pair political preferences are related to (unobserved) bank-level characteristics. However, we acknowledge that political preferences may be related to other time-variant bilateral linkages between countries that may be related to bank soundness. Nevertheless, we consider this to be less likely in our case since political preferences in this setting are mostly related to war and human rights matters voting, thus not related to the banking system. Hence, we argue that bilateral variation in voting patterns is plausibly expected to be exogenous to bank soundness.

We thus exploit variations in bilateral affinity to obtain (predicted) cooperation intensities. Specifically, we run a duration model of cooperation[2] on lagged political affinity for all country-pairs in our sample over the entire sample

[1] Specifically, Dell'Ariccia and Marquez (2006) show gains to cooperation increase when regulators have more homogenous preferences. Outside banking, preference similarities have been identified as the primary determinant of fiscal centralization (see Oates (1972)).

[2] As we explain in detail in Section 4.2.2. in the paper, duration analysis is appropriate in our setting (while a standard panel analysis is not) due to the specific time-structure of the dependent variable (in particular, countries never move from cooperation to no cooperation).

period, and obtain (time-varying) estimated probabilities from the model. The results reported in column (3) confirm that political affinity predicts cooperation; the affinity coefficient is positive and significant at the 1% level.

In a second step, we calculate *bank-specific* instruments from the country-pair cooperation propensities using the subsidiary structure at the beginning of the sample period as we did in the model in column (2), to account for changes in the subsidiary structure. The first stage regression of the IV is reported in column (4). While there is a strong positive and significant relationship between the predicted cooperation and actual cooperation, the F-statistic is less than 10 (4.3), which suggests that the instrument may be weak. Hence, in the second-stage results reported in column (5), we use the Anderson Rubin Wald test, which allows for robust inference in the case of weak instruments. The results in this column confirm our previous finding of a positive relationship between supervisory cross-border cooperation and bank stability: the estimated coefficient is positive and significant (p-value equals 5.2%). Furthermore, the p-value of the Anderson Rubin Wald test suggests we can reject the null that the cooperation coefficient is equal to zero in this model.[3] The higher coefficient compared to the corresponding OLS coefficient in Table 2 suggests the presence of reverse causation captured by the OLS coefficient (as higher bank fragility may increase the likelihood of cooperation, per Figure A.1).[4]

We cannot run overidentification tests in this model since the equation is just identified. However, we conduct a crude test of the instrumental variable's exclusion restriction by regressing residuals from the second stage in model (5) on the *Cooperation fixed IV* variable. The p-value of this test is 1.00, which suggests our instrument is valid.

As a fourth test, we examine whether effectiveness is reduced (or even disappears) during crisis times. We add an interaction term between cooperation and a dummy for the GFC (column 6). While cooperation continues to enter positively and significantly, its interaction with the crisis dummy enters positively and insignificantly. This suggests that supervisory cooperation is not weakened during

[3]We have also run the Conditional Likelihood Ratio test to obtain confidence intervals robust to weak instruments for the cooperation coefficient. This test confirms our findings; the cooperation coefficient is positive and statistically significant in the IV model.

[4]An alternative explanation could be that financial integration leads to both higher cooperation and lower bank stability, which biases the OLS coefficient downwards.

crisis periods.

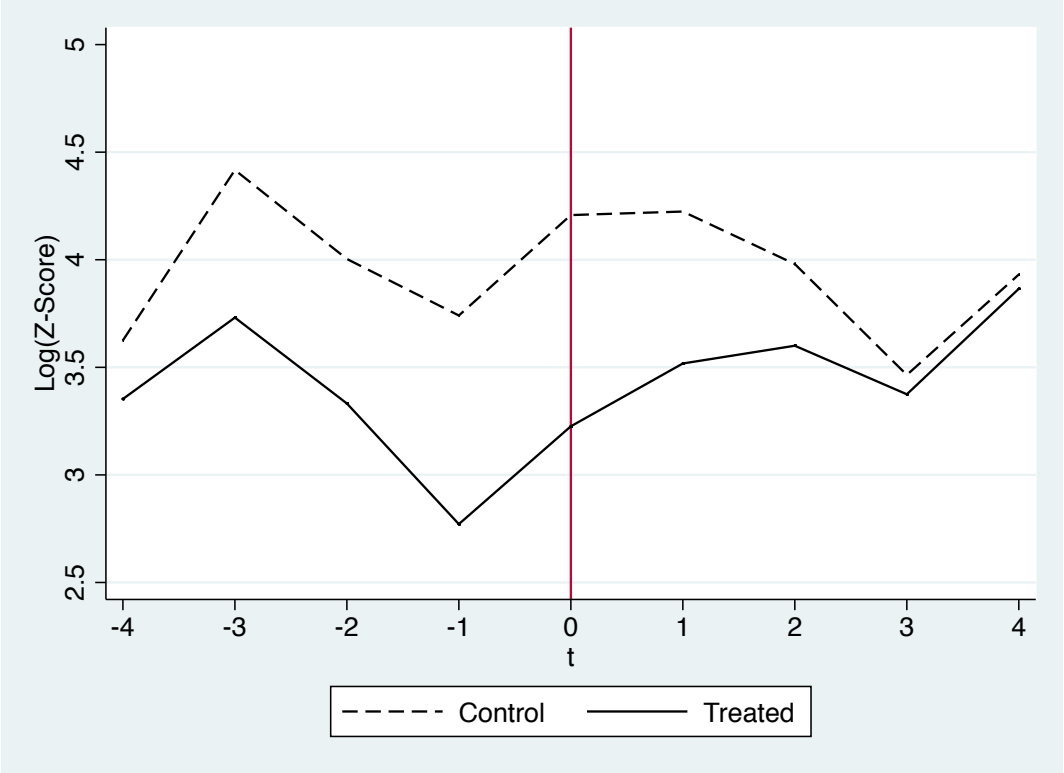
As a final robustness test, we examine the presence of non-linearities in the relationship between supervisory cooperation and bank stability by adding the square of the cooperation index (column 7). Cooperation may arguably only become effective once it covers a wide part of the bank's subsidiaries (as long as there are some subsidiaries not covered by cooperation, the bank can always shift risk there), suggesting that the effectiveness of cooperation increases with the level of cooperation. The squared term is positive and marginally significant (p-value 0.11), and linear and quadratic terms are jointly significant (p-value=0.005), indicating that there may be increasing returns to supervisory cooperation.

Table A.2: Robustness

	Lagged	Lagged + structure fixed	IV + structure fixed			Crisis	Cooperation intensity
				1st stage	2nd stage		
	Log(Z-Score)	Log(Z-Score)	Country-pair Cooperation	Cooperation	Log(Z-Score)	Log(Z-Score)	Log(Z-Score)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Cooperation_{t-1}$	0.701**						
	(0.304)						
$Cooperation\ fixed_{t-1}$		0.677**					
		(0.300)					
$Affinity_{t-1}$			8.150***				
			(2.644)				
Cooperation fixed IV				0.956**			
				(0.456)			
Cooperation					3.883*	0.894***	1.721***
					(1.998)	(0.330)	(0.586)
Cooperation*Crisis						0.625	
						(0.495)	
$Cooperation^2$							2.493
							(1.535)
F - statistic				4.3			
Anderson Rubin Wald test (p-value)					0.02		
Exclusion test (p-value)					1.00		
All controls	Y	Y	N	Y	Y	Y	Y
Bank FE	Y	Y	N	Y	Y	Y	Y
Year FE	Y	Y	N	Y	Y	Y	Y
Observations	399	399	3,576	193	193	402	402
R-squared	0.19	0.19		0.35		0.22	0.22

This table presents the results of regressions of bank risk on cooperation. The dependent variables are a bank's *Log(Z-Score)* in columns (1), (2), (5), (6) and (7), country-pair cooperation in column (3), and the bank-level cooperation indicator in column (4). *Cooperation* equals the asset-weighted cooperation dummy between the parent bank country and its subsidiaries' countries. $Cooperation_{t-1}$ if the one-year lag *Cooperation* indicator. $Cooperation\ fixed_{t-1}$ equals the one-year lag of the asset-weighted cooperation dummy between the parent bank country and the countries of its subsidiaries in the bank's first period in our sample. $Affinity_{t-1}$ equals one-year lag of the the similarity of voting patterns in the U.N. General Assembly. *Cooperation fixed IV* equals the asset-weighted predicted cooperation dummy between the parent bank country and the countries of its subsidiaries in the bank's first period in our sample. *Crisis* is a dummy variable equal to one starting in 2008. *Cooperation* is mean centered in column (7). The regressions contain the sample of small banks only. The sample period spans from 1995-2013. Definitions and sources of control variables are listed in Appendix D. All regressions are estimated including bank and year fixed effects and robust standard errors clustered at the bank level (in parentheses). ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Figure A.1. Parallel trends



The figure shows the average *Log(Z-Score)* by time and treatment group. A bank is defined as treated if the yearly change in the bank's asset-weighted cooperation indicator is larger than the 75th percentile of this change. A bank is defined as control if it did not sign any agreement during our sample period. Treated banks are matched to control banks in the same country and year. The vertical line indicates the time when a bank increases cooperation according to the treatment definition.

Appendix F: Duration model

Unlike commonly used logit or probit models, which measure the unconditional probability of the occurrence of an event, duration models estimate the conditional probability of an event at time t, given that no event has occurred until this time. If T is a non-negative random variable denoting time to cooperation, then duration models define a survival function $S(t)$ which is the reverse cumulative distribution of T: $S(t) = 1 - F(t) = P(T > t)$, where $F(t)$ is the cumulative distribution function of the probability density function $f(t)$. Thus, the survival function reports the probability of surviving beyond time t. The average probability that the event occurs in a given interval, conditional on the subject having survived to the beginning of that interval is defined as,

$$h(t) = \lim_{\Delta t \to 0} \frac{P(t + \Delta t > T > t | T > t)}{\Delta t} = \frac{f(t)}{S(t)}. \tag{2}$$

This average probability is called the hazard function. Following the literature (e.g. Ongena and Smith (2001)), we assume the following proportional hazard specification

$$h(t, X(t), \beta) = \lim_{\Delta t \to 0} \frac{P(t + \Delta t > T > t | T > t, X(t), \beta)}{\Delta t} = h_0(t) exp(\beta^{'} X_t). \tag{3}$$

where X_t are time varying controls (the externality and heterogeneity indices in our context). The term $h_0(t)$ is the baseline hazard function, which determines the shape of the hazard function with respect to time. We estimate this model assuming an exponential distribution, fitting a baseline hazard which is constant over time.