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JEL Classification: D8, G11, G2

Keywords: Multinational bank, supervisory intervention, supranational supervision, voluntary support, ring-fencing

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1 Introduction

Cross-border banks (CBBs) often use a subsidiary structure for operating in multiple countries. While the subsidiary structure enables the parent bank to walk away from the losses of a distressed unit, CBBs often forgo such limited liability option. During the global financial crisis (GFC) and the European sovereign debt crisis, many struggling subsidiaries of European banking groups benefited from capital and liquidity support from healthier units within their banking groups. Prominent examples are the Baltic subsidiaries of some Swedish banks (Fiechter et al., 2011).[1,2]

These actions were scrutinized by the national supervisory authorities of the banking groups, who were concerned about the potential costs for their domestic deposit insurance funds of extending support to impaired foreign operations.[3] Some national authorities imposed asset maintenance requirements or restrictions on intragroup transactions, measures referred to as *ring-fencing*, in order to protect stakeholders of the banks' local operations.[4] For example, Austrian supervisors—worried about an increase in non-performing loans—tried to push Austrian banks to reduce lending to their Eastern and Central European subsidiaries (The Wall Street Journal, May 31, 2012).

In the aftermath of the GFC, there is renewed regulatory discussion on addressing ring-fencing along national lines (see, e.g., Bénassy-Quéré et al., 2018; Enria and Fernandez-Bollo, 2020; Financial Stability Board, 2020).[5] On the one hand, it is recognized that the

[1]Some foreign banks operating in Portugal under a subsidiary structure switched to a branch organization structure during the peak of the European Sovereign debt crisis, which effectively amounts to forgoing limited liability protection over their subsidiaries (Bonfim and Santos, 2019). An earlier example of voluntary support is the recapitalization by the Portuguese bank Banco Espiritu Santo of its Brazilian subsidiary Banco Boavista Interatlantico following the devaluation of the Brazilian real in 1999.

[2]More generally, during crisis periods banks also provided voluntary support to other off-balance sheet sponsored entities such as securitization vehicles (e.g., Higgins and Mason, 2004; Gorton and Souleles, 2007; Vermilyea et al., 2008; Acharya et al., 2013) and money market mutual funds (e.g., Brady et al., 2012; Kacperczyk and Schnabl, 2013).

[3]More broadly, these costs could also stem from an eventual need to bailout the parent banks due to the loss-transfer associated with support.

[4]European Commission (2010) reviews limitations that are imposed on the direction of the transfers whether it is from the parent to the subsidiary institution or vice-versa and Basel Committee on Banking Supervision (2010) acknowledges the strong incentives for ring fencing in a crisis and develops a set of recommendations for cross-border crises resolutions.

[5]More discussion on this debate can be found in, e.g., Enria (2019), Lautenschläger (2019), and Enria (2020).

expectation of ring-fencing of liquidity and capital resources along jurisdictional lines during crises could lead to inefficient resource allocation or reduced diversification, with negative consequences on financial stability. This is in line with the literature that emphasizes the benefits of multinational banking groups stemming from a centralized capital and liquidity management (De Haas and Van Lelyveld, 2010; Cetorelli and Goldberg, 2012) or from intra-group support (Nicodano and Regis, 2019; Segura and Zeng, 2020). On the other hand, it is acknowledged that national authorities remain reluctant to forgo their ring-fencing prerogatives because of fears that such support provision could lead to a higher cost of bank crises for domestic taxpayers. Ring-fencing is therefore recognized as one of the main obstacles to achieving cooperation between supervisory authorities that could produce gains for all parties involved.

This paper provides a theoretical contribution to the ring-fencing debate in the context of supervisory intervention in an impaired subsidiary of a cross-border bank. Specifically, the questions we aim to address are: First, when does ring-fencing limit cross-unit voluntary support and how does this affect the efficiency of the intervention outcome? Second, how does the anticipation of ring-fencing impact on the cross-border bank's risk taking incentives? Finally, under what condition would the establishment of a supranational authority be welfare improving, and is it compatible with the interests of national authorities to protect national deposit insurance funds?

We first show that ring-fencing emerges in the supervisory intervention of an impaired subsidiary of a CBB under national architecture when the correlation between the subsidiaries' assets is high. Ring-fencing results in either costly external capital raising or the inefficient liquidation of the impaired unit. In contrast, a supranational architecture eliminates ring-fencing. This result highlights the costs of a national supervisory architecture in environments in which an increasing economic integration leads to high correlation between the CBB units' assets. Next, we show that the supervisory architecture by affecting the mutual support possibilities across subsidiaries also has an impact on the CBB's risk choices. We find that the elimination of ring-fencing through a supranational architecture leads to a convergence of the subsidiary risk across CBBs that differ in their fundamentals. Finally, taking into account both the effects of the institutional architecture on the supervisory intervention outcome and the bank's risk-taking incentives, we evaluate the two architectures by comparing expected deposit insurance costs and overall welfare. We show that a supranational architecture reduces the expected deposit insurance costs only for riskier banks, and that in those cases such architecture is overall welfare maximizing. Interestingly, for (moderately) safer banks, a supranational architecture is overall welfare maximizing but it might not be a feasible arrangement because it leads to an increase in expected deposit insurance costs.

We model a CBB that has a pure holding structure and that owns and manages two ex ante identical operating subsidiaries in two countries. At the initial date, each subsidiary (henceforth unit) is financed with one unit of fully insured deposits and has a portfolio of loans (henceforth assets). The CBB is managed by its risk-neutral utility maximizer owner (henceforth the banker). At the interim date, each unit can be either healthy or impaired, and costly and unobservable effort exerted by the banker in the unit at the initial date increases the probability of the unit being healthy. If a unit becomes impaired at the interim date, a process of supervisory intervention starts in which the CBB may choose to recapitalize the unit in order to avoid its liquidation by the responsible authority. Should the CBB's other unit be healthy, the CBB may recapitalize the impaired unit with a (subordinated) intra-group loan from the healthy unit. We refer to such cross-border transfer of resources as *voluntary support*, which enables the bank to avoid the costs of raising external capital.[6] Yet, since providing voluntary support increases the riskiness of the healthy unit, its responsible authority may only approve such support if it is accompanied by a recapitalization of the healthy unit. We refer to this as *ring-fencing* of the healthy unit, as it is an obstacle to cross-unit capital flows and limits the extent to which the CBB can benefit from recapitalizing its impaired unit through voluntary support.

We compare two supervisory architectures for the intervention in an impaired unit of the CBB. Under a national architecture, there are two national authorities that take decisions non-cooperatively within their jurisdictions with the aim of minimizing their respective deposit insurance costs. Under a supranational architecture, a single supranational authority takes decisions for both units in order to minimize the overall deposit insurance costs in the

[6] Such costs can stem from the scarcity of risk bearing capital or from information asymmetry.

two countries. We show that the institutional architecture affects outcomes not only in the intervention process but also ahead of it, as it influences the bank's incentives to exert effort in order to avoid intervention.

We first analyze supervisory intervention in an impaired unit. We show that the CBB would like to recapitalize the impaired unit using exclusively internal resources from the other unit if the latter is healthy. Under a national architecture, however, ring-fencing of the healthy unit arises if the correlation between the two units' asset payoffs is high. That is, the CBB is required to raise costly capital at the healthy unit by its responsible authority in order to compensate for the risks associated with extending the intra-group loan. The intuition for this result is as follows. The provision of voluntary support affects the healthy unit's deposit insurance costs in two opposing ways. On the one hand, these costs are reduced at the final date when the healthy unit fails and the impaired unit succeeds: the intragroup loan is repaid and the proceeds are used to (partially) reimburse the healthy unit's depositors. On the other hand, these costs are increased when both units simultaneously fail and the intragroup loan is not repaid. The second effect dominates for high correlation, leading to the ring-fencing of the healthy unit; that is, the authority requires a recapitalization of the healthy unit in order to approve the provision of voluntary support. The severity of ring-fencing, i.e., the amount of external equity issuance required to the healthy unit to provide support, is increasing in the correlation. For sufficiently high correlation, the cost of equity issuance outweighs the net efficiency gain from avoiding the impaired unit's liquidation, and the CBB does not choose to provide cross-unit support.

Under a supranational architecture, by contrast, ring-fencing never arises even for high correlation between the CBB units' assets. This is because a supranational authority, who aims at protecting both deposit insurance funds, is willing to allow a larger support to the impaired unit using the healthy unit's available resources. A larger voluntary support increases the deposit insurance cost to the healthy unit, but decreases the deposit insurance cost to the impaired unit. Overall, the latter effect dominates and a larger voluntary support reduces the two countries' total deposit insurance cost. This is because the impaired unit defaults with a higher probability so that following support the CBB funds are more likely to contribute to reducing the deposit insurance costs. Therefore the supranational authority is willing to allow the recapitalization of the impaired unit with a larger intra-group loan without requiring any costly external equity issuance.

We next focus on the case of a high correlation between the CBB units' assets, and analyze how the different intervention outcomes of an impaired unit under the two institutional architectures affect the banker's effort in each of the units. The elimination of ring-fencing by a supranational architecture has two opposing effects. There is a positive *support giving effect*: Since effort increases the probability that a unit is healthy, eliminating ring-fencing increases the marginal value of effort as a healthy unit may provide voluntary support to the other unit. Importantly, this effect arises because the banker makes coordinated effort choices for its two units, so that the effort choice of one unit internalizes the benefit from voluntarily supporting the other unit. There is also a negative *support receiving effect*: The elimination of ring-fencing reduces the disciplining effect of liquidation or costly equity issuance on the banker's incentives to exert effort. The relative strength of the two effects depends on the (exogenous) drivers of the CBB's units risks. For banks with riskier units, it is more likely that the units become ex post impaired, which then increases the strength of the support giving effect and reduces that of the support receiving effect. We have thus that the elimination of ring-fencing increases the banker's effort for riskier banks. The converse is true for safer banks. The model thus predicts that the establishment of a supranational architecture should lead to a risk convergence across CBBs with heterogeneous fundamentals.

We finally evaluate the two institutional architectures, taking into account their impact on both the supervisory intervention process and the banker's effort. If the correlation between the CBB's units' asset payoffs is low, both institutional architectures lead to identical outcomes. If the correlation is high, however, a supranational architecture eliminates ring-fencing in the intervention of an impaired unit, and increases (decreases) the banker's effort for riskier (safer) CCBs. Since higher effort increases the probability that the CBB's units are healthy, a supranational architecture lowers the expected deposit insurance costs for riskier banks. In these cases, the welfare gains from higher banker effort add to those from a more efficient supervisory intervention process, and the supranational architecture also maximizes aggregate welfare. Interestingly, a supranational architecture may be aggregate welfare maximizing even in situations in which it leads to lower banker effort and thus higher deposit insurance costs in the two countries. We show this is the case for moderately safe banks. In these cases, although welfare would improve under a supranational architecture, national supervisors might oppose delegating their authority to a supranational supervisor.

Related literature

Our paper relates to the literature on the supervision of cross-border banks. This literature highlights cross-border externalities that result in frictions and conflicts between national authorities. Consequently, independent national authorities may choose suboptimal policies in the form of low capital adequacy standards (Acharya, 2003; Dell'Ariccia and Marquez, 2006), underprovision of public funds to recapitalize failing banks (Freixas, 2003; Goodhart and Schoenmaker, 2009), too coarse information sharing (Holthausen and Rønde, 2004), too little supervisory monitoring (Calzolari et al., 2018), or inefficient resolution (Bolton and Oehmke, 2019). We complement the existing literature by considering supervisory intervention in a scenario in which one unit of the cross-border bank becomes impaired while the other remains healthy. Our perspective gives rise to a strategic interplay between the bank's incentives to provide voluntary support and the authorities' incentives to ring-fence the healthy unit.[7]

Several papers in this literature discuss the optimal supervisory architecture. While a supranational architecture may circumvent the frictions between national authorities, such an arrangement may not be incentive compatible when countries are heterogeneous (Goodhart and Schoenmaker, 2009; Bolton and Oehmke, 2019). In addition, supranational supervision may entail loss of flexibility if equal standards must be applied across jurisdictions (Dell'Ariccia and Marquez, 2006; Beck and Wagner, 2016), may worsen the quality of information collected by national authorities (Colliard, 2020; Carletti et al., 2021), and may induce unintended consequences as CBBs strategically adjust their organizational structure (Calzolari et al., 2018). We contribute to this discussion by showing that, first, a supranational architecture improves the efficiency of intervention outcomes by eliminating ring-fencing, and second, this can have positive or negative effects on the CBB's (effort) incentives.

Finally, this paper is related to the theoretical literature that studies the role of voluntary

[7]In contrast, Bolton and Oehmke (2019) considers ring-fencing of the CBB in resolution, in which the CBB is no longer viable and ring-fencing amounts to limits on how the resolution authority(ies) can directly reallocate resources across the CBB's units.

support to a distressed subsidiary. While we emphasize such voluntary support as an outcome of bargaining with the supervisory authority of the distressed subsidiary, there are other contributions in which voluntary support to off-balance sheet structures arise to avoid a run on the bank's short-term liabilities (Segura, 2017), to signal positive information about future investment opportunities (Segura and Zeng, 2020), to maintain sponsor reputation (Ordoñez, 2018), to avoid costly liquidation of long-term assets (Kobayashi and Osano, 2012), to conserve the fees associated with these activities (Parlatore, 2016), or as a form of collusion between the bank and investors (Gorton and Souleles, 2007; Kuncl, 2019).

2 The Model

There are three dates $t = 0, 1, 2$ and no time discounting. A CBB operates two units, in countries A and B, under a bank holding company (BHC) structure. The bank is managed by its risk-neutral owner, whom we henceforth refer to as the banker. Each unit is organized as a subsidiary which at the initial date has assets and deposits with notional value normalized to one. Each unit's deposits are fully insured by the national deposit insurance fund of the country in which it is located.[8] Deposits mature at $t = 2$ and each subsidiary is subject to limited liability, hence each unit deposits are repaid at $t = 2$ only with the payoffs of that unit's assets. The BHC initially owns all the equity of the subsidiaries and the banker takes decisions to maximize its expected payoff. Depending on the institutional architecture, there are two national authorities or a single supranational authority that take decisions at $t = 1$ to protect the interest of national deposit insurance funds.

The bank's assets At $t = 0$, each unit $i \in \{A, B\}$ has assets that generate a certain interim payoff $r > 0$ at $t = 1$, and a final payoff $R > 0$ at $t = 2$ in case of success, or 0 in case of failure. For simplicity, we assume that the CBB can repay in full all its deposits only if both units succeed at $t = 2$:

Assumption 1. $R + 2r < 2 < 2R + 2r$.

[8] Deposits are held by some unmodeled depositors, who play no active role in the model due to the presence of deposit insurance.

The success probability of each unit's assets depends on the unit type: Healthy unit assets succeed at $t = 2$ with high (h) probability p_h, while impaired unit assets with low (ℓ) probability p_ℓ, where $p_h > p_\ell$.

Unit types are realized at $t = 1$ and depend on the unobservable effort exerted by the banker at $t = 0$. Specifically, if she exerts effort $e^i \in [0, 1]$ for unit i, the unit is healthy with probability $\gamma + e^i$, and impaired with complementary probability $1 - \gamma - e_i$. We can interpret the parameter γ as measuring the bank's fundamentals, and assume that it is bounded from above by some $\bar{\gamma} < 1$. We say that a larger (smaller) γ corresponds to a safer (riskier) bank. We assume that the realization of unit type at $t = 1$ is independent given the banker's effort decisions. Exerting effort e^i entails an increasing and convex private disutility cost $k(e^i)$ for the banker. We assume that the cost function $k(e^i)$ is increasing and sufficiently convex, which ensures a unique interior solution to the banker's effort problem:

Assumption 2. *$k(0) = 0, k'(0) = 0, k'(1 - \bar{\gamma}) \to \infty$, $k''(e) \geq 2(p_\ell R - L)$, and $k'''(e) \geq 0$.*

Conditional on unit types at the interim date, the two units' final payoffs can be correlated. In practice, the extent of this correlation may depend on the similarities of the productive sector in the two countries and on their level of financial integration. This correlation will be one of the key parameters in the model because it determines potential conflicts in the CBB's supervision between the banker and the authority(ies).

Specifically, we capture the correlation between the final payoffs of the two units by a parameter $\rho \in [0, 1]$, such that for success probabilities of the two units at $t = 1$ given by $p^A, p^B \in \{p_h, p_\ell\}$, the probability that both units succeed at $t = 2$ is $\rho \min\{p^A, p^B\}$. It follows that the probability that only unit i succeeds is $p^i - \rho \min\{p^A, p^B\}$ for all $i \in \{A, B\}$, and the probability that both units fail is $1 - p^A - p^B + \rho \min\{p^A, p^B\}$.[9] Hence, for $\rho = 1$, the payoffs of the two units are maximally positively correlated (i.e., the unit with lower success probability can succeed only if the other unit succeeds); and for $\rho = 0$, they are maximally negatively correlated (i.e., both units cannot succeed simultaneously). For $\rho = \max\{p^A, p^B\}$, the payoffs of the two units are independent. Table 1 summarizes the joint payoff distribution

[9]Notice that, if $p_h \leq \frac{1}{2}$, for any $\rho \in [0, 1]$ all the joint probabilities are in the interval $[0, 1]$. Otherwise, ρ can only take values within a subset of $[0, 1]$, in order to ensure that all joint probabilities are in the interval $[0, 1]$.

		Unit B	
		R	0
Unit A	R	$\rho \min\{p^A, p^B\}$	$p^A - \rho \min\{p^A, p^B\}$
	0	$p^B - \rho \min\{p^A, p^B\}$	$1 - p^A - p^B + \rho \min\{p^A, p^B\}$

Table 1: Joint probability distribution of unit A and B's assets' $t = 2$ payoffs conditional on the units' asset success probabilities at $t = 1$.

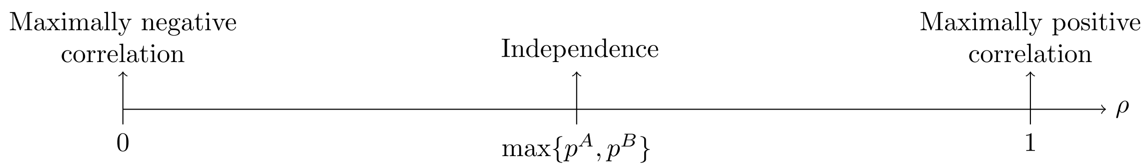

Figure 1: Parametrization of the correlation between the unit A and B's $t = 2$ payoffs conditional on the units' asset success probabilities at $t = 1$.

and Figure 1 graphically illustrates the effect of the variable ρ on the correlation between the two units' payoffs.

Institutional architecture There is a supervisory authority responsible for each unit of the CBB that can take actions at the interim date in order to minimize deposit insurance costs. We distinguish between a *national architecture*, in which two different national authorities are responsible for the unit in their jurisdiction and each of them makes decisions uncooperatively to minimize the expected cost of deposit insurance in its jurisdiction, and a *supranational architecture*, in which a single supranational authority is in charge of both units and aims at minimizing the sum of deposit insurance costs of the two countries.

Supervisory intervention At $t = 1$, unit types are realized. Based on this information, the responsible authority of a unit may decide to intervene by requiring the *recapitalization* of the unit. If the unit is not recapitalized as requested, the authority can decide whether to *liquidate* it. Liquidation can involve removing the unit banking licence, liquidating its assets and shutting down its activities. More generally, it can be thought of as a supervisory action that protects the interests of deposit insurance funds at the expense of the unit's shareholders (the banker), which could take the form of restrictions on investing in certain assets, mandatory disposal of non-performing loan portfolios or divestment requirements from some non core businesses. For concreteness, we assume that liquidation results in a certain payoff L that satisfies the following:

Assumption 3. *(i) $p_\ell R > L$; (ii) $p_h > \frac{L}{1-r} > p_\ell$.*

Part (i) of this assumption states that intervention reduces the expected payoff of the assets. However, since it also reduces the unit's riskiness, an authority may wish to liquidate a unit if it reduces its deposit insurance costs. In fact, part (ii) of this assumption implies that liquidation lowers the expected deposit insurance cost of an impaired unit but not that of a healthy unit. This implies that, in the absence of any recapitalization, the authority prefers to liquidate if and only if the unit is impaired. This set up captures the situation in which the arrival of negative information about the unit's quality triggers a supervisory intervention in which the CBB is offered the possibility to recapitalize its unit under the threat of liquidation.

Each unit can be recapitalized with a combination of i) external capital, by issuing equity at a net rate of return $c > 0$, and ii) internal capital, by injecting resources from the other unit through an intragroup (subordinated) loan. We will henceforth refer to the latter means of recapitalizing a CBB's unit as *voluntary support*.[10] Formally, a recapitalization plan of the CBB at $t = 1$, $\big(\{x^i\}_{i\in\{A,B\}}, \{\phi^i\}_{i\in\{A,B\}}, s, S\big)$, consists of i) a fraction $\phi_i \in [0,1]$ of unit i equity issued to external capital providers in exchange for $x^i \geq 0$ units of funds for $i \in \{A,B\}$, and ii) an intragroup loan described by a cross-unit injection of funds s in exchange of a promised repayment S at $t = 2$ that is junior to outstanding deposits. We denote by $s, S \geq 0$ a loan from unit A to unit B, and by $s, S \leq 0$ a loan from unit B to unit A. The resulting balance sheets of the two units are illustrated in Figure 2. Notice that choosing not to recapitalize coincides with the recapitalization plan $\big(\{x^i = 0\}_{i\in\{A,B\}}, \{\phi^i = 0\}_{i\in\{A,B\}}, s = 0, S = 0\big)$.

Since the repayment of the intragroup loan can be risky, the authority responsible for the healthy unit may not approve the provision of voluntary support to the impaired unit unless it is accompanied by some recapitalization of the healthy unit.[11] We interpret this as

[10]The cost of external capital can stem from scarcity of resources or (unmodeled) asymmetric information, and gives rise to a role for internal capital markets.

[11]This could be interpreted as the introduction by the responsible authority of a capital requirement add-on for the issuance of an intragroup loan.

Unit A

Assets	Liabilities
Asset A of quality p_A	Deposits (1)
Intragroup loan to unit B (s, S)	Equity – External (ϕ_A) – BHC $(1 - \phi_A)$
Cash $(r + x_A - s)$	

Unit B

Assets	Liabilities
Asset B of quality p_B	Deposits (1)
	Intragroup loan from unit A (s, S)
Cash $(r + x_B + s)$	Equity – External (ϕ_B) – BHC $(1 - \phi_B)$

Figure 2: Balance sheets of units A and B given a recapitalization plan $\big(\{x_i\}_{i\in\{A,B\}}, \{\phi_i\}_{i\in\{A,B\}}, s, S\big)$, assuming an intragroup loan from unit A to unit B (i.e., $s, S \geq 0$).

ring-fencing of the healthy unit, as it puts obstacles to cross-unit capital flows.

We formally model the intervention process at $t = 1$ described above as follows, which succinctly accounts for the potential interdependency between the recapitalization of the CBB's two units discussed above. After each unit type is realized, the banker first proposes a recapitalization plan. The authority responsible for each unit then decides whether to approve the recapitalization plan. Under a national architecture, the recapitalization plan is implemented and both units are allowed to continue only if it is approved by both national authorities; under a supranational architecture, it is implemented (and both units are allowed to continue) if it is approved by the single supranational authority. Finally, if the recapitalization plan is not implemented, the responsible authority for each unit decides whether to liquidate its unit or let it continue.

To highlight the tension between voluntary support and ring-fencing, we assume that:

Assumption 4. *i)* $r \geq \frac{L-p_\ell}{1-2p_\ell}$, *and ii)* $c \geq \frac{1-p_\ell}{L-p_\ell(1-r)}(p_\ell R - L)$.

As will become clear later, the first condition in the assumption implies that a healthy unit has sufficient interim payoff to provide the entire recapitalization required to avoid the liquidation of an impaired unit. The second condition instead implies that the cost of external equity is so high that recapitalization of an impaired unit entirely with external equity issued by that unit is not feasible.

Timeline The sequence of events and decisions is summarized in Figure 3. At $t = 0$, the banker exerts effort e^i in each unit $i \in \{A, B\}$. At $t = 1$, after each unit's assets' interim

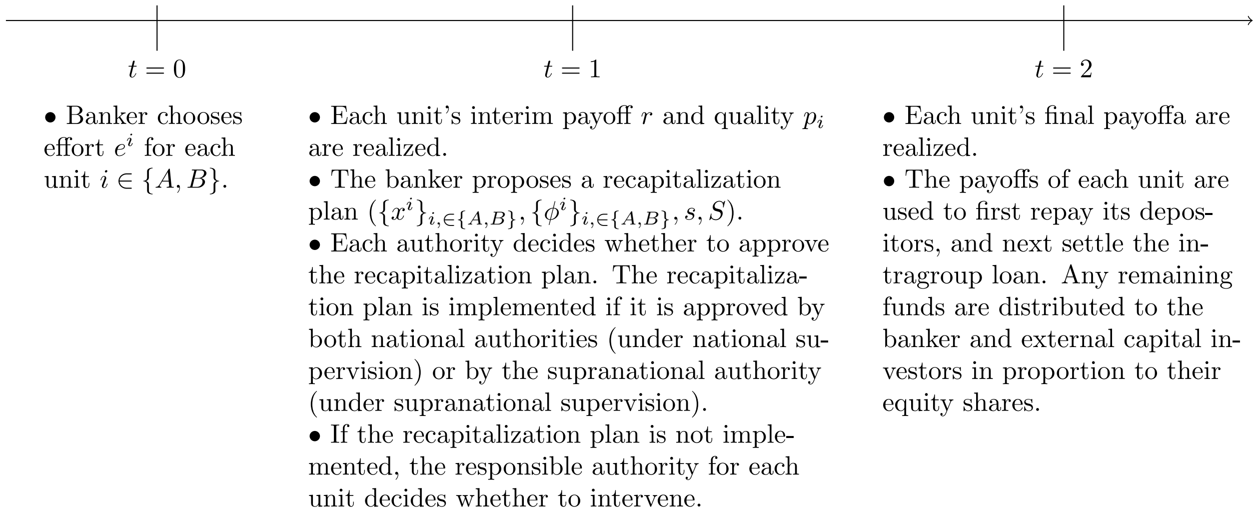

Figure 3: Time line.

payoff r and their type are realized, the decisions of the players are as follows. The banker first proposes a recapitalization plan $\left(\{x^i\}_{i\in\{A,B\}}, \{\phi^i\}_{i\in\{A,B\}}, s, S\right)$. The recapitalization plan is then implemented if it is approved by both national authorities (under national architecture) or by the supranational authority (under supranational architecture). If a recapitalization plan is not implemented, the responsible authority for each unit decides whether to liquidate the unit. At $t = 2$, each unit's final payoffs are realized. These payoffs are used first to repay its deposits, and next to settle the intragroup loan (if any). Any remaining funds in each of the units are distributed to the banker and external capital investors in proportion to their equity shares in the units.

3 Equilibrium Analysis

This section solves for the equilibrium under a national architecture and a supranational architecture separately, and finally analyzes the optimal institutional architecture from an aggregate welfare maximizing perspective and from a deposit insurance cost minimizing perspective.

3.1 Equilibrium under a national architecture

To characterize the equilibrium under a national architecture, we proceed by backward induction. We first characterize the national authorities' interventions to minimize their respective national deposit insurance costs and the banker's incentives to provide voluntary support at $t = 1$. We then solve for the bankers' effort choice at $t = 0$.

Intervention in an impaired unit: Voluntary support and ring-fencing Let us first focus on the case at $t = 1$ in which one of the bank units is healthy and the other unit is impaired. This is the interesting scenario in which voluntary support and ring-fencing may arise. The outcomes in the other possible scenarios are discussed later.

For concreteness, we assume unit A is healthy and unit B is impaired. That is, at $t = 1$, after the interim payoff r realizes in each unit, units A and B succeed at $t = 2$ with probabilities $p^A = p_h$ and $p^B = p_\ell$, respectively, if they continue.

Suppose first there is no recapitalization, either because the banker does not propose any recapitalization plan or because it is rejected by at least one of the authorities. Authority i does not liquidate unit i if and only if

$$(1 - p^i)(1 - r) \leq 1 - L - r. \tag{1}$$

The left- and right-hand side in the expression above account for the expected deposit insurance cost in country i in case of continuation and liquidation of the unit, respectively. Notice that the interim payoff r serves to reduce deposit insurance costs if the authority does not lquidate the unit and it fails at $t = 2$ (with probability $1 - p^i$), as well as if the authority liquidates the unit. By Assumption 3, condition (1) is satisfied for unit A (whose assets succeed with probability p_h) and not for unit B (whose assets succeed with probability p_ℓ).

The banker therefore may wish to propose a recapitalization plan $\left(x^A, x^B, s, S\right)$ that is accepted by the two authorities and avoids the liquidation of unit B. Without loss of generality, we restrict attention to recapitalization plans that include an intragroup loan from unit A to unit B, that is, with $s, S \geq 0$.[12] The recapitalization plan must satisfy the

[12] Assumption 4 implies that it is unfeasible for unit B to raise sufficient external capital to avoid its liquidation while lending to unit A.

following budget constraint:

$$S \leq R + (r + x^B + s) - 1, \tag{2}$$

which states that the promised repayment on the intragroup loan is bounded above by unit B's available cash in case of success at $t = 2$ net of the deposit repayments. The expression accounts for the funds injected in unit B at $t = 1$ from both the external equity issuance, x^B, and the intragroup loan, s.[13]

A recapitalization plan is accepted by authority B if and only if its expected deposit insurance cost is lower with recapitalization than without, that is, if

$$C_1^B(x^B, s) \equiv (1 - p_\ell)\left[1 - (r + x^B + s)\right] \leq 1 - L - r. \tag{3}$$

The expected deposit insurance cost in country B in case of approval, denoted by $C_1^B(x^B, s)$, depends only on the overall external and internal capital injection in unit B, $x^B + s$, and is strictly decreasing in this amount.[14] This implies that from authority B's perspective, recapitalization through external equity issuance x_B and through intragroup loan s are perfect substitutes. Furthermore, by (3) and Assumption 3, authority B requires a strictly positive minimum overall recapitalization $x^B + s$ in order to avoid the liquidation of unit B.

Similarly, a recapitalization plan is accepted by authority A if and only if its expected deposit insurance cost is lower with recapitalization (and continuation of unit B) than without (and liquidation of unit B), that is, if

$$C_1^A(x^A, s, S|\rho) \equiv (1 - p_h)\left[1 - (r + x^A - s)\right] - (1 - \rho)p_\ell S \leq (1 - p_h)(1 - r). \tag{4}$$

The expected deposit insurance cost in country A in case of approval, denoted by $C_1^A(x^A, s, S|\rho)$, depends only on the choice variables (x_A, s, S) and is composed of two terms. The first term captures that, following the recapitalization plan, unit A carries $r + x^A - s$ units of funds

[13] Notice that the recapitalization plan must also satisfy the budget constraint $s \leq r + x^A$, which states that the amount of the intragroup loan is bounded from above by unit A's interim payoff plus any external funds raised. However, it is easy to verify that this constraint never binds in any optimal recapitalization plan.

[14] For the sake of notational simplicity, the expression assumes that $r + x^B + s \leq 1$ so that upon failure of unit B the deposit insurance fund makes some losses. We show in the proof of Proposition 1 that the this condition is indeed satisfied by the optimal recapitalization plan.

to $t = 2$.[15] These funds serve to reduce the deposit insurance costs in case of failure of unit A at $t = 2$, which happens with probability $1 - p_h$. This term is decreasing in the external equity issuance of unit A, x^A, and increasing in the size of the voluntary support, s, which highlights the benefit of external equity issuance and the cost of voluntary support provision for authority A. The second term captures that when unit B succeeds and unit A fails, which happens with probability $(1-\rho)p_\ell$, the intragroup loan is repaid and contributes towards reducing the deposit insurance cost in country A. This term highlights the benefit of voluntary support provision for authority A, which is increasing in the intragroup loan promise S and decreasing in the correlation parameter ρ, because the higher the correlation between the two units' assets the less likely it is that unit B succeeds when unit A fails.

We have from (4) that for any intragroup loan (s, S) there is a minimum equity issuance $x^A \geq 0$ authority A requires in order to accept the recapitalization plan, and such capital injection is increasing in the correlation ρ between the two units. When such required capital injection is strictly positive, we say that authority A *ring-fences* unit A as it is putting obstacles to the cross-unit capital flow.

Let us now consider the banker's optimal recapitalization decision. If a proposed recapitalization plan is not approved by both authorities, or if the banker chooses not to recapitalize, authority B liquidates unit B and the banker's $t = 1$ expected payoff, consisting of the residual payoff of unit A at $t = 2$, is given by:

$$\underline{\Pi}_1 = (p_h R + r - 1) + (1 - p_h)(1 - r). \tag{5}$$

The expression decomposes the equity value of unit A's as the present value of its assets net of its nominal deposit liability plus the expected cost of unit A's deposit insurance, which amounts to a subsidy appropriated by the banker.

If a recapitalization plan is approved by both authorities, the banker's expected payoff as of $t = 1$ can be expressed as follows:

$$\Pi_1(x^A, x^B, s, S) = (p_h R + r - 1) + (p_\ell R + r - 1) + C_1^A(x^A, s, S|\rho) + C_1^B(x^B, s) - (x^A + x^B)c. \tag{6}$$

[15] For the sake of notational simplicity, the expression for $C_1^A(x^A, s, S|\rho)$ in (4) assumes that $x^B + s \leq 1$ and $r + x^A - s + S \leq 1$ which implies that upon failure of any of the units, its deposit insurance fund must incur some cost. In the proof of Proposition 1 we show that the these conditions are indeed satisfied by the optimal recapitalization plan.

The first two terms in the decomposition above capture the asset values of each unit net of its nominal deposit liability. The third and fourth terms account for the expected deposit insurance cost in each unit, which is a subsidy appropriated by the banker. The final term captures the cost of raising external capital, since investors ask for an excess expected return $c > 0$.[16]

Subtracting (5) from (6), we have that the expected payoff difference for the banker between a recapitalization plan that is approved and no recapitalization is:

$$\Pi_1(x^A, x^B, s, S) - \underline{\Pi}_1 = (p_\ell R - L) - \left[(1 - p_h)(1 - r) - C_1^A(x^A, s, S|\rho)\right] - \left[(1 - L - r) - C_1^B(x^B, s)\right] - (x^A + x^B)c. \quad (7)$$

The expression is composed of four terms. The first one captures the value gains from the continuation of unit B, since $L < p_\ell R$. The second and third term capture how much of the value gains from the continuation are appropriated by each of the authorities. From (3) and (4) these terms must be weakly positive for a recapitalization plan that is approved by the two authorities. Finally, the fourth term accounts for the excess return required by external equity investors, which reduces the expected payoff appropriated by the banker. The expected profit decomposition in (7) highlights that the banker will try to design a recapitalization plan that i) is just compatible with the authorities' approval in order to avoid value appropriation by the authorities; and ii) relies as little as possible on external equity issuance since it is costly. The next proposition characterizes the solution to the banker's recapitalization problem.

Proposition 1. *Suppose at $t = 1$ unit A is healthy and unit B is impaired. Under a national architecture, there exist $\underline{\rho}, \overline{\rho} \in (p_h, 1)$, with $\underline{\rho} < \overline{\rho}$, such that the unique equilibrium of the supervisory intervention at $t = 1$ is as follows.*

- *If $\rho \leq \overline{\rho}$, the banker's optimal recapitalization plan avoids the liquidation of unit B, binds both authorities' approval conditions (3) and (4), and consists of*
  - *an intragroup loan from unit A to unit B, $(s^*, S^*(\rho))$, where $s^* = \frac{L - p_\ell(1-r)}{1-p_\ell}$ and $S^*(\rho)$ is strictly increasing in ρ for $\rho \leq \underline{\rho}$ and $S^*(\rho) = R + r + s^* - 1$ for $\rho \in [\underline{\rho}, \overline{\rho}]$,*

[16] The equity shares ϕ_i promised to external equity investors do not appear explicitly in (6), because we have derived the expression using the fact that any external equity issued is fairly priced.

– *no external equity issuance for unit B,* $x^B = 0$*, and*

– *external equity issuance for unit A,* $x^A = x_h^*(\rho)$*, where* $x_h^*(\rho)$ *satisfies* $x_h^*(\rho) = 0$ *for* $\rho \leq \underline{\rho}$*, is strictly increasing in* ρ *for* $\rho > \underline{\rho}$*, and* $x_h^*(\overline{\rho}) = \frac{p_\ell R - L}{c}$.

- *If* $\rho > \overline{\rho}$*, there no recapitalization is undertaken and unit B is liquidated.*

To understand this proposition, consider first the case in which a recapitalization plan that avoids the liquidation of unit B is undertaken. This occurs when the correlation between the two units' final payoffs is not too high, i.e., $\rho \leq \overline{\rho}$. The results in this case highlight the role of *voluntary support* in the recapitalization of unit B to avoid its liquidation. The necessary amount of recapitalization is provided exclusively through an intragroup loan from unit A of the amount s^*, rather than through costly external equity issued by unit B, i.e., $x^B = 0$. Moreover, the amount of capital injection s^* is chosen to be the minimum that binds authority B's approval constraint (3) in order to maximize the banker's expected payoff given by (6).

Interestingly, the correlation between the two units' final payoffs shapes the terms of the intragroup loan and the amount of external equity issued by unit A in the banker's optimal recapitalization plan. To maximize the banker's expected payoff, the optimal recapitalization plan binds authority A's approval constraint (4) while minimizing costly external equity issuance. For negative or small correlation between the units ($\rho < \underline{\rho}$, where $\underline{\rho} > p_h$, and recall that for $\rho = p_h$ the two units are independent, see Figure 1), no external equity is issued $x_h^*(\rho) = 0$, and the promised repayment on the intragoup loan S^* is set to satisfy authority A's approval constraint. Notice that the promised repayment S^* required by authority A in exchange for approving the voluntary support to unit B is increasing in the correlation ρ. This is because as the correlation increases, it becomes less likely that the repayment of the intragroup loan contributes to reducing the deposit insurance costs in country A (which happens only if unit A fails while unit B succeeds, with probability $(1 - \rho)p_\ell$).

As the correlation between the two units becomes large ($\rho > \underline{\rho}$), authority A is unwilling to authorize a voluntary support s^* even when the promised repayment on the intragroup loan exhausts the residual payoff of unit B ($S^* = R + s^* - 1$). As a result, ring-fencing by authority A occurs, that is, the authority requires a strictly positive equity issuance $x_h^*(\rho)$ in

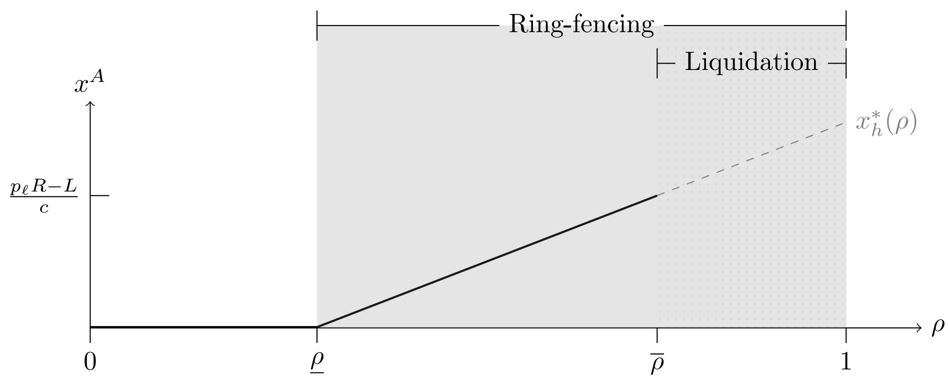

Figure 4: The severity of ring-fencing under a national architecture. $x_h^*(\rho)$ represents the minimum amount of external equity issuance $x_h^*(\rho)$ required by authority A in exchange for approving the voluntary support to unit B. The CBB recapitalizes and issues $x^A = x_h^*(\rho)$ amount of external equity only if the cost of recapitalization, $x_h^*(\rho)c$, is lower than the benefit of avoiding the liquidation of unit B, $p_\ell R - L$.

unit A in exchange for approving the voluntary support to unit B. In other words, authority A requires that part of the voluntary support be financed with external equity issuance, even though by Assumption 4 unit A has enough internal resources to provide the entire capital required by unit B to avoid its liquidation. The amount of external equity required by authority A is increasing in the correlation between the two units, as the probability that the repayment of the intragroup loan contributes to reducing the deposit insurance costs in country A is decreasing in that variable. Figure 4 illustrates that ring-fencing arises for $\rho > \underline{\rho}$ (the light shaded area), and that the severity of ring-fencing (as measured by $x_h^*(\rho)$) is increasing in ρ.

Ring-fencing by authority A therefore limits the extent to which the CBB can save on costly external equity through voluntary support, and reduces the banker's profits from recapitalizing unit B to avoid its liquidation. For intermediate levels of positive correlation ($\rho \in (\underline{\rho}, \overline{\rho}]$), the banker finds it optimal to provide voluntary support to unit B despite ring-fencing and the need to raise costly external capital. However, for high levels of positive correlation ($\rho > \overline{\rho}$), the banker no longer finds it optimal to provide voluntary support to unit B, which is consequently liquidated. This is illustrated by the dotted area in Figure 4.

Finally, we briefly describe the outcome under the other two possible scenarios at $t = 1$. If both units are healthy, then (1) holds for the two units in the absence of any recapitalization.

Hence, no recapitalization is undertaken and the authorities do not liquidate. In this case there is, indeed, no supervisory intervention at the interim date. If both units are impaired, we have from (3) that each authority requires a minimum recapitalization of $\frac{L-p_\ell(1-r)}{1-p_\ell}$ for its unit. Yet, Assumption 4 implies that equity issuance is so costly that neither unit is able to obtain the required amount of capital. Supervisory intervention in this case does not result in the recapitalization of the units, and each authority liquidates the unit under its responsibility.

Banker's effort choice at $t = 0$ We now study the banker's effort choice for each unit at $t = 0$. The effort decision is jointly determined for the two units and takes as given the $t = 1$ equilibrium we have just analyzed. Proposition 1 has shown that the correlation between the two units' final payoffs determine the supervisory intervention outcome at $t = 1$. Specifically, recall that $x_h^*(\rho)$ denotes the minimum external equity issuance required by the authority supervising the healthy unit in exchange for providing voluntary support to the impaired unit, while the CBB chooses to recapitalize and issue this amount of external equity only if $\rho \leq \bar{\rho}$. Taking this into account, we have that for any correlation ρ between the units and a pair of effort choices (e^A, e^B) at $t = 0$, the banker's expected payoff as of $t = 0$ can be expressed as:

$$\Pi_0(e^A, e^B; x_h^*(\rho)) \equiv \sum_{i \in \{A,B\}} (\gamma + e^i) p_h (R + r - 1) - k(e_i) \\ + \underbrace{\left[(\gamma + e^A)(1 - \gamma - e^B) + (1 - \gamma - e^A)(\gamma + e^B)\right]}_{\text{Probability of voluntary support}} \underbrace{\left[(p_\ell R - L) - x_h^*(\rho) c\right]^+}_{\text{Support gains}}, \tag{8}$$

The first term of this expression represents the banker's expected payoff in the absence of voluntary support. In this case, the banker receives the entire residual claim of unit i at $t = 2$ only if it is of h quality at $t = 1$, which occurs with probability $(\gamma + e^i)$. The second term in this expression, which is strictly positive only for $\rho < \bar{\rho}$, represents the increase in the banker's expected payoff stemming from the voluntary support from the h quality unit to the ℓ quality unit. In this case, the banker's increase in payoff from voluntary support is equal to the gains from the continuation of the ℓ quality unit, $p_\ell R - L$, net of the excess cost of the external equity issuance whenever ring-fencing arises, $x_h^*(\rho)c$. The superscript "+" captures the fact that ring-fencing may render it too costly for the CBB to recapitalization the impaired unit and avoid its intervention. It follows from the properties of $x_h^*(\rho)$ that this term is equal to zero if and only if $\rho \geq \overline{\rho}$.[17]

We have from (8) that the banker's optimal effort choice pair (e^A, e^B) satisfies the following set of first order conditions that equalize marginal effort cost and benefit:

$$k'(e^i) = p_h(R + r - 1) + \left[\underbrace{1 - (\gamma + e^j)}_{\text{Support giving}} - \underbrace{(\gamma + e^j)}_{\text{Support receiving}}\right] \left[(p_\ell R - L) - x_h^*(\rho)c\right]^+, \qquad (9)$$

where $i, j \in \{A, B\}$ denote two different units. The first term on the right-hand side of (9) represents the marginal benefit of effort in the absence of voluntary support between units.

The second term on the right-hand side of (9) represents the additional effect of effort due to the possibility of voluntary support. There are two opposing effects. On the one hand, the possibility of voluntary support increases the marginal benefit of effort for unit i, since effort increases the probability that unit i can provide support *to* unit j in case the latter becomes impaired, which occurs with probability $1 - (\gamma + e^j)$. We henceforth refer to this as the *support giving effect*. Importantly, this effect arises because the banker makes coordinated effort choices for its two units, so that the effort choice for unit i internalizes its effect on unit j's profitability. This effect is weaker if γ is higher: a lower probability that unit j is impaired reduces the marginal benefit to exert effort for unit i as voluntary voluntary support for unit j is less needed.

On the other hand, the possibility of voluntary support *from* unit j reduces the marginal benefit of effort for unit i. This is because, when unit i is impaired, it may avoid a liquidation via voluntary support from unit j if the latter is healthy, which occurs with probability $\gamma + e^j$. Therefore voluntary support reduces the disciplining effect of a potential liquidation and thus effort incentives. We henceforth refer to this as the *support receiving effect*. Notice that this effect is stronger if γ is higher, as a higher probability that unit j is healthy implies a larger reduction in the liquidation threat.

Moreover, the magnitude of both the support giving and the support receiving effects

[17]As shown in the proof of Proposition 1, $x_h^*(\rho)$ is strictly increasing in ρ for $\rho \in [\underline{\rho}, 1]$ and satisfies $x_h^*(\rho) \geq \frac{p_\ell R - L}{c}$ if and only if $\rho \geq \overline{\rho}$.

depends on the correlation between the units' final payoffs ρ through the last two terms in the second term of the right-hand side of (9). Recall from Proposition 1 that ring-fencing becomes more severe as the correlation increases, as the amount $x_h^*(\rho)$ of costly external equity required by the authority responsible for a healthy unit in exchange for providing voluntary support is increasing in ρ. Furthermore, ring-fencing is so severe for $\rho > \overline{\rho}$ that no voluntary support is provided. As a result, ring-fencing dampens both effects proportionally.

The following proposition then follows from (9) and the properties of $x_h^*(\rho)$ given by Proposition 1.

Proposition 2. *Under a national architecture, the banker's optimal effort choice is $e^*(\rho, \gamma)$ in each unit $i \in \{A, B\}$, and satisfies the following properties.*

- *For $\rho \leq \underline{\rho}$, $e^*(\rho, \gamma) = e^{**}(\gamma)$, where $e^{**}(\gamma)$ is defined by*

$$k'(e^{**}(\gamma)) = p_h(R + r - 1) + [1 - 2(\gamma + e^{**}(\gamma))] (p_\ell R - L). \tag{10}$$

- *For $\rho > \underline{\rho}$, there exists a threshold $\underline{\gamma}$ independent from ρ, such that,*
  - *if $\gamma \leq \underline{\gamma}$, $e^*(\rho, \gamma) \leq e^{**}(\gamma)$ and $e^*(\rho, \gamma)$ is decreasing in ρ;*
  - *if $\gamma \geq \underline{\gamma}$, $e^*(\rho, \gamma) \geq e^{**}(\gamma)$ and $e^*(\rho, \gamma)$ is increasing in ρ.*

The threshold $\underline{\rho}$ is defined in Proposition 1.

This proposition shows how the bankers' effort depends on the CBB's fundamentals, γ, and the correlation between the two units' final payoffs, ρ. While the correlation determines the emergence of ring-fencing and the associated value destruction for the banker, the bank fundamentals determine whether the support receiving or the support giving effect dominates. The results are illustrated in Figure 5. For riskier banks ($\gamma \leq \underline{\gamma}$), the positive support giving effect dominates. Effort is thus maximum when correlation between the units is not too large and ring-fencing does not emerge ($\rho \leq \underline{\rho}$). As correlation increases and ring-fencing arises and becomes progressively more severe ($\rho > \underline{\rho}$), the bankers' effort gets reduced. Effort is minimum when correlation between the two units is so severe that impaired units are liquidated and no value is appropriated by the banker ($\rho \geq \overline{\rho}$). The effect of correlation between the units on the banker's effort is reversed for safer banks ($\gamma \geq \underline{\gamma}$), for which the negative support receiving effect dominates and ring-fencing increases the banker's effort. Notice that, when ring-fencing is so severe that no voluntary support takes place and the impaired unit is liquidated, both the support giving and the support receiving effects vanish. In this case, the banker's effort does not depend on the CBB's fundamentals.

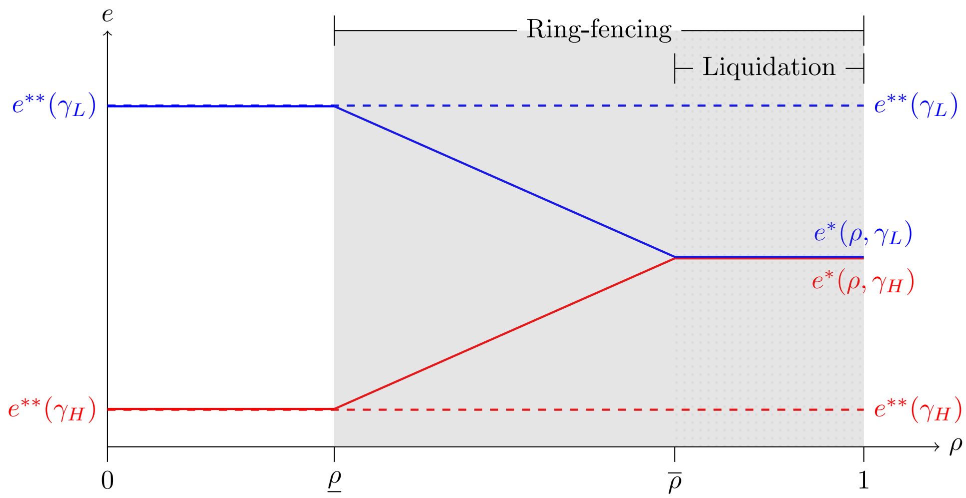

Figure 5: The banker's optimal effort choice under a national architecture $e^*(\rho, \gamma)$ illustrated for two values of γ, γ_H and γ_L, where $\gamma_H > \underline{\gamma} > \gamma_L$.

3.2 Equilibrium under a supranational architecture

In this section, we characterize the equilibrium under a supranational architecture. Recall that in this institutional setup, each country pays the costs associated with the deposit insurance of the unit in its jurisdiction, but a single supranational authority takes decisions at $t = 1$ to minimize the overall deposit insurance cost in the two countries. We again proceed by backward induction, characterizing first the supranational authority's action and the banker's incentives to provide voluntary support at $t = 1$, and then the bankers' effort choice at $t = 0$.

Intervention in an impaired unit: Voluntary support without ring-fencing We again focus on the interesting case at $t = 1$, in which one of the units is healthy and the other unit is impaired. For all other scenarios it is easy to check that the outcome is identical to that under a national architecture.

Suppose that unit A is healthy and unit B is impaired. In the absence of any recapitalization, Assumption 3 and (1) imply that the total deposit insurance cost is minimized if the supranational authority only liquidates unit B. The banker may thus decide to propose a recapitalization plan $\left(x^A, x^B, s, S\right)$ to prevent liquidation of unit B. Using the notation for the expected deposit insurance cost in each country introduced in (3) and (4), we have that the supranational authority accepts the recapitalization plan if and only if the total expected deposit insurance cost in both countries is lower with recapitalization than without, that is, if

$$\underbrace{C_1^A(x_A, s, S|\rho)}_{unit\ A} + \underbrace{C_1^B(x_B, s)}_{unit\ B} \leq \underbrace{(1-p_h)(1-r)}_{unit\ A} + \underbrace{(1-L-r)}_{unit\ B}. \tag{11}$$

Notice that the single recapitalization approval condition (11) under a supranational architecture is implied by the two national approval conditions (3) and (4) under a national architecture. Hence, if a recapitalization plan is approved under a national architecture, it is also approved under a supranational architecture. The converse is not true, as the supranational authority would approve a recapitalization plan that reduces the total deposit insurance cost, even if it increases the expected deposit insurance cost in one of the countries. By exempting from the issue of *redistribution* of deposit insurance costs across countries, the supranational authority is more lenient towards letting unit B continue.

For a recapitalization plan $\left(x^A, x^B, s, S\right)$, the banker's expected payoff as of $t = 1$ is given by (6) if it is approved and by (5) if it is not. The banker's optimal recapitalization problem is thus analogous to that under a national architecture discussed in Section 3.1 with the difference that approval conditions (3) and (4) are replaced with (11). Whenever the banker's optimal recapitalization plan is not unique, we will focus on the recapitalization plan that leads to the lowest deposit insurance cost redistribution across countries. The next proposition characterizes the solution to the optimal recapitalization problem.

Proposition 3. *Suppose at $t = 1$ unit A is healthy and unit B is impaired. Under a supranational architecture, any banker's optimal recapitalization plan ensures the continuation of unit B, binds the supranational authority's approval condition (11), and involves no external equity issuance, i.e., $x^A = x^B = 0$.*

In particular, the optimal recapitalization plan that minimizes deposit insurance cost redistribution between the two countries is described by an intragroup loan from unit A to unit B, $(s^{**}(\rho), S^{**}(\rho))$, with the following properties.

- *If $\rho \leq \underline{\rho}$, then $s^{**}(\rho) = s^*$ and $S^{**}(\rho) = S^*(\rho)$.*
- *If $\rho > \underline{\rho}$, then $s^{**}(\rho) > s^*$ for $\rho \in (\underline{\rho}, \overline{\rho}]$ and is strictly increasing in ρ for all $\rho > \underline{\rho}$, and $S^{**}(\rho) = R + s^{**}(\rho) - 1$.*

The thresholds, $\underline{\rho}$ and $\overline{\rho}$, and the intragroup loan $(s^*, S^*(\rho))$ are defined in Proposition 1.

Proposition 3 states that, for low correlation between the two units' final payoffs ($\rho \leq \underline{\rho}$), the optimal recapitalization plan proposed by the banker under a national architecture is also optimal under a supranational architecture. This is due to two reasons. First, since it ensures that the expected cost for each national deposit insurance fund is not higher with than without recapitalization, it also satisfies the capital requirements by the supranational authority, with no redistribution of deposit insurance costs across countries. Second, since it does not require the CBB to issue costly equity, it maximizes the banker's expected payoff.

For higher correlation between the two units' final payoffs ($\rho > \underline{\rho}$), the banker proposes a recapitalization plan under a supranational architecture that consists of a larger intragroup loan compared to that under a national architecture, i.e., $s^{**}(\rho) > s^*$ and $S^{**}(\rho) > S^*(\rho)$, and no external equity issuance. To understand this result, recall that, for all $\rho > \underline{\rho}$, an intragroup loan of the amount s^* ensures that refraining from intervening in unit B does not increase the expected deposit insurance cost to country B, but strictly increases the expected deposit insurance cost to country A even when the promised repayment is maximized at $S^*(\rho) = R + s^* - 1$. This is the reason why ring-fences arises under national architecture and authority A requires a recapitalization of unit A to approve support to unit B. Suppose that the intragroup loan s is increased above s^*. The left-hand side of (11) captures how that affects the total deposit insurance cost to the two countries. On the one hand, a larger intragroup loan s reduces the deposit insurance cost to country B if unit B fails. On the other hand, a larger intragroup loan s increases the deposit insurance cost to country A if unit A fails *and* unit B fails. It is worth noting that, if unit A fails but unit B succeeds, the increase in the intragroup loan does not affect the deposit insurance cost to country A, since it also increases one-to-one the residual profit of unit B that can be used to repay the intragroup loan (because $S = R + s - 1$). This shows that the reduction in the deposit insurance cost to country B is larger than the increase in the deposit insurance cost to country A, and a larger intragroup loan therefore reduces the total expected deposit insurance cost to the two countries. Thus, the supranational authority, who minimizes the total deposit insurance cost to the two countries, is willing to accept a recapitalization plan that involves a larger intragroup loan, without requiring the bank to raise additional capital.

Moreover, Proposition 3 states that the amount of intragroup loan required by the supranational authority, $s^{**}(\rho)$, is increasing in the correlation between the two units' final payoffs. This is because, as the correlation increases, the benefit of the continuation of unit B accrues less often to unit A's depositors in the form of repayment of the intragroup loan. The supranational authority thus requires a higher intragroup loan in order to compensate for the total deposit insurance cost to the two countries.

We have thus established that the supranational authority's willingness to allow redistribution of deposit insurance costs across countries avoids the emergence of ring-fencing, that is, the bank can prevent the liquidation of unit B without having to raise costly equity. As a result, in equilibrium the bank provides support for any level of correlation, and the value destroying liquidation of unit B never arises.

Banker's effort choice at $t = 0$ The characterization of the bank's effort choice at $t = 0$ under a supranational architecture is analogous to that under a national architecture. Since the bank's optimal recapitalization plan allows the continuation of an impaired unit via voluntary support from a healthy unit without resorting to external equity issuance, the banker's expected payoff is given by $\Pi_0(e^A, e^B; 0)$ (see expression (8)). The first order condition that characterizes the banker's effort choice at $t = 0$ is thus given by

$$k'(e^i) = p_h(R + r - 1) + \left[1 - 2(\gamma + e^j)\right](p_\ell R - L) \; \forall i, j \in \{A, B\} \textit{ and } i \neq j, \tag{12}$$

which is analogous to (9), with the only difference that voluntary support arises for all ρ and the equity issuance of the healthy unit is always $x_h^*(\rho) = 0$ due to the absence of ring-fencing. The next result follows immediately.

Proposition 4. *Let $e^{**}(\gamma)$, $e^{*}(\rho,\gamma)$, and $\underline{\gamma}$ be the variables defined in Proposition 2. The banker's optimal effort choice under a supranational architecture is $e^{**}(\gamma)$ in each unit $i \in \{A, B\}$, and satisfies the following properties.*

- *For $\rho \leq \underline{\rho}$, the banker's optimal effort choice under a supranational architecture coincides with that under a national architecture, i.e., $e^{**}(\gamma) = e^{*}(\rho,\gamma)$.*
- *For $\rho > \underline{\rho}$, the banker's optimal effort choice is higher under a supranational architecture than under a national architecture, i.e., $e^{**}(\gamma) \geq e^{*}(\rho,\gamma)$, if and only if $\gamma \leq \underline{\gamma}$.*

Proposition 4 shows that the banker's optimal effort under a supranational architecture depends only on the CBB's fundamentals, γ, but not on the correlation between the two units, ρ, as was the case for a national architecture (Proposition 2). In addition, effort coincides under the two architectures when correlation between the two units is not too high ($\rho \leq \underline{\rho}$), so that the two architectures achieve the same recapitalization outcome when a unit is impaired and the other unit is healthy (Proposition 3).

The banker's effort under a supranational architecture differs from that under a national architecture when there is a high positive correlation ($\rho > \underline{\rho}$), and ring-fencing arises under the latter but not under the former. The effect on the banker's effort of eliminating ring-fencing depends on the CBB's fundamentals, as this variable determines which of the support giving or receiving effects discussed in Section 3.1 dominates. For riskier banks ($\gamma \leq \underline{\gamma}$), the positive support giving effect dominates, ring-fencing is detrimental for effort, and the banker exerts more effort under a supranational architecture. For safer banks ($\gamma \geq \underline{\gamma}$), the negative support receiving effect dominates, ring-fencing incentivizes effort, and the banker exerts less effort under a supranational architecture. The comparison between the bank's optimal effort under a national and a supranational architecture is illustrated in Figure 5.

Importantly, Proposition 4 implies that supranational architecture leads to a convergence of the subsidiary risk of banks with heterogeneous fundamentals, γ, where risk is measured by the probability ($\gamma + e^{i}$) that a subsidiary remains healthy at $t = 1$. This is illustrated in Figure 6.

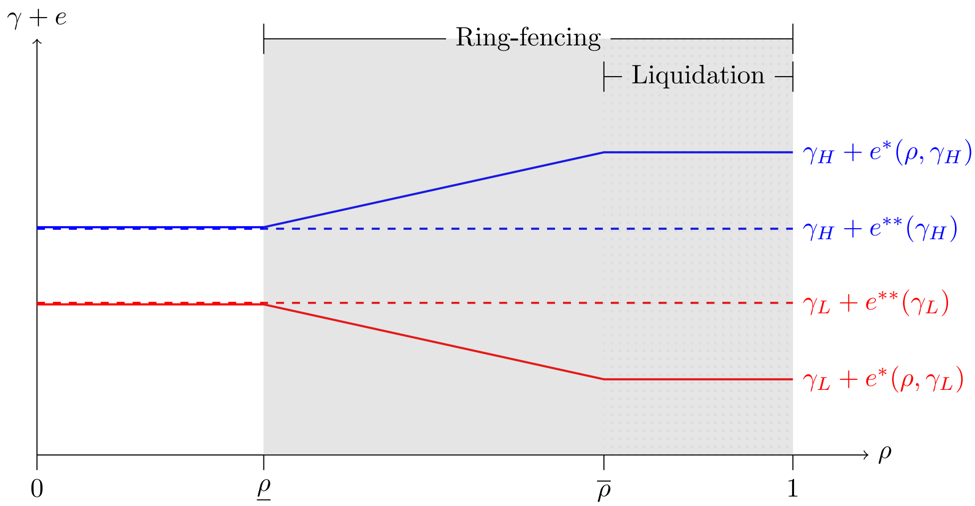

Figure 6: The equilibrium subsidiary risk of a CBB under a national architecture, $\gamma+e^*(\rho,\gamma)$, and under a supranational architecture, $\gamma + e^{**}(\gamma)$, illustrated for two values of γ, γ_H and γ_L, where $\gamma_H > \underline{\gamma} > \gamma_L$.

3.3 Optimal institutional architecture

We conclude this section by evaluating the optimality of the national and supranational architecture from two different perspectives. First, we consider the deposit insurance costs of each country. This allows us to assess whether the establishment of a supranational architecture is compatible with national interests. Second, we consider overall welfare, which is equal to the CBB's expected payoff less the sum of two countries' deposit insurance costs. This allows us to assess the efficiency of the two institutional architectures and to understand whether there can be conflicting national interests that hinder the establishment of an efficient institutional architecture.

Expected deposit insurance cost We compute the expected deposit insurance cost in each country, taking as given the banker's effort choice at $t = 0$ and subsequently the intervention outcome of an impaired unit at $t = 1$. Under a national architecture, recall from Proposition 1 that even when there is voluntary support from a healthy to an impaired unit at the interim date (that is, for $\rho \leq \overline{\rho}$), the expected deposit insurance cost in each country coincides with that under no voluntary support (that is, the authorization constraints (3) and (4) are binding). Taking this into account, we have that for any correlation ρ the expected deposit insurance cost in country $i \in \{A, B\}$ as of $t = 0$ is given by $C_0(e^*(\rho, \gamma))$, where $C_0(e)$ is defined as

$$C_0(e) = (\gamma + e)\,(1 - p_h)(1 - r) + (1 - \gamma - e)\,(1 - L - r), \tag{13}$$

and $e^*(\rho, \gamma)$ denotes the optimal effort choice of each unit under a national architecture and has the properties described in Proposition 2. The two terms in the expression above capture the expected deposit insurance cost for healthy units, $(1-p_h)(1-r)$, and for impaired units, $1 - L$, weighted by their respective probabilities.

Under a supranational architecture, recall from Proposition 3 that voluntary support from a healthy to an impaired unit at the interim date binds the authority's participation constraint (11), so that the total expected deposit insurance costs in the two countries coincide with those under no voluntary support, although there may be redistribution between them. Yet, since the two countries are ex ante identical, the expected redistribution from a $t = 0$ perspective nets out to 0. Taking this into account, we have that for any correlation ρ the expected deposit issuance cost in country $i \in \{A, B\}$ as of $t = 0$ is given by $C_0(e^{**}(\gamma))$, where $e^{**}(\gamma)$ denotes the optimal effort choice in each unit under a supranational architecture and has the properties described in Proposition 4.

Notice that, since each authority's approval constraints are kept binding at the bank's optimal recapitalization plan, the authorities do not benefit directly from the efficiency gains from recapitalizing an impaired unit via voluntary support to avoid its liquidation. However, the expected deposit insurance cost in each country is influenced by the the recapitalization outcome of an impaired unit indirectly through the banker's effort choices: the expected deposit insurance cost $C_0(e)$ given in (13) is strictly decreasing in the banker's effort level, e. This is because effort increases the probability that a unit is healthy at the interim date, and by Assumption 3, the deposit insurance cost for a (non-intervened) healthy unit is lower than that for an (intervened) impaired unit. The next result then follows immediately from Proposition 4.

Proposition 5. *Let $\underline{\rho}, \underline{\gamma}$ be the thresholds defined in Proposition 1 and 2, respectively. We have that:*

- *For $\rho \leq \underline{\rho}$, the expected deposit insurance cost in each country is identical under a* *national and a supranational architecture.*

- *For $\rho > \underline{\rho}$, the expected deposit insurance cost in each country is lower under a supranational architecture than under a national architecture if and only if $\gamma \leq \underline{\gamma}$.*

For negative or small positive correlations between the units' final payoffs ($\rho \leq \underline{\rho}$), since both supervisory architectures lead to the same recapitalization of an impaired unit at $t = 1$ and thus the same effort choice by the banker at $t = 0$, supervisory architecture does not matter for the expected deposit insurance cost in each country. This is not the case for high correlation ($\rho > \underline{\rho}$). A supranational architecture lowers the expected deposit insurance cost in each country for riskier banks ($\gamma \geq \underline{\gamma}$). This is because for riskier banks the positive support giving effect on effort dominates, and a supranational architecture by removing ring-fencing leads to higher effort by the banker. In contrast, a supranational architecture increases the expected deposit insurance costs in each country for safer banks ($\gamma \leq \underline{\gamma}$), for which the negative support receiving effect dominates and the elimination of ring-fencing through supranational support is detrimental for the bankers' effort.

Welfare Let us turn to consider the overall welfare in the economy, which takes into account not only the expected deposit insurance cost in each country, but also the expected profit of the CBB. Recall that this is given by $\Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma); x_h^*(\rho))$ and $\Pi_0(e^{**}(\gamma), e^{**}(\gamma); 0)$ under a national and a supranational architecture, respectively, where $\Pi_0(e_A, e_B; x_h)$ is define by (8). Overall welfare is thus given by $W(e^*(\rho,\gamma); x_h^*)$ and $W(e^{**}(\gamma); 0)$ under a national and a supranational architecture, respectively, where

$$W(e; x_h) = \Pi_0(e, e; x_h) - 2C_0(e). \tag{14}$$

Notice that the CBB's expected payoff is higher under a supranational architecture than under a national architecture. This is because the CBB captures the direct benefit from the continuation of the impaired unit under a supranational architecture. To see this, we have

$$\begin{aligned}
&\Pi_0(e^{**}(\gamma), e^{**}(\gamma); 0) - \Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma); x_h^*(\rho)) \\
=\ &[\Pi_0(e^{**}(\gamma), e^{**}(\gamma); 0) - \Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma); 0)] \\
&\qquad + [\Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma); 0) - \Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma); x_h^*(\rho))] > 0,
\end{aligned} \tag{15}$$

where the first term is positive by the optimality of the banker's effort choice, and the second term captures the direct positive effect of eliminating ring-fencing under a supranational supervision. The following proposition compares welfare under the two institutional architectures.

Proposition 6. *Let $\underline{\rho}, \underline{\gamma}$ be the thresholds defined in Proposition 1, and 2, respectively.*

- *For $\rho \leq \underline{\rho}$, welfare is identical under a supranational architecture and under a national architecture.*
- *For $\rho > \underline{\rho}$, there exists $\tilde{\gamma}(\rho) > \underline{\gamma}$, such that welfare is higher under a supranational architecture than under a national architecture if and only if $\gamma \leq \tilde{\gamma}(\rho)$.*

For negative or small positive correlation between the units' final payoffs ($\rho \leq \underline{\rho}$), both institutional architectures lead to the same supervisory intervention outcomes and thus the same welfare. For high correlation ($\rho > \underline{\rho}$), whether a supranational architecture improves welfare depends on the CBB's fundamentals.

For riskier banks ($\gamma \leq \underline{\gamma}$), a supranational architecture eliminates ring-fencing when correlation between units is high. The improved efficiency of the intervention of an impaired unit at $t = 1$ also has a net positive effect on the banker's effort choice at $t = 0$ as the support giving effect dominates. Welfare is therefore unambiguously higher under a supranational architecture.

For safer banks ($\gamma > \underline{\gamma}$), the elimination of ring-fencing has a net negative effect on the banker's effort choice at $t = 0$ as the support receiving effect dominates. For banks with intermediate fundamentals ($\gamma \in (\underline{\gamma}, \tilde{\gamma}(\rho)]$), the net effect of eliminating ring-fencing on the banker's effect choice is small, as the support giving effect and the support receiving effect roughly balances each other. As a result, overall welfare increases under a supranational architecture because of the efficient continuation of the impaired unit despite the lower effort. For sufficiently strong banks ($\gamma > \tilde{\gamma}(\rho)$), the reduction in the banker's effect can be so large that overall welfare is lower under a supranational architecture.

The next result immediately follows from Propositions 5 and 6, and is illustrated in Figure 7.

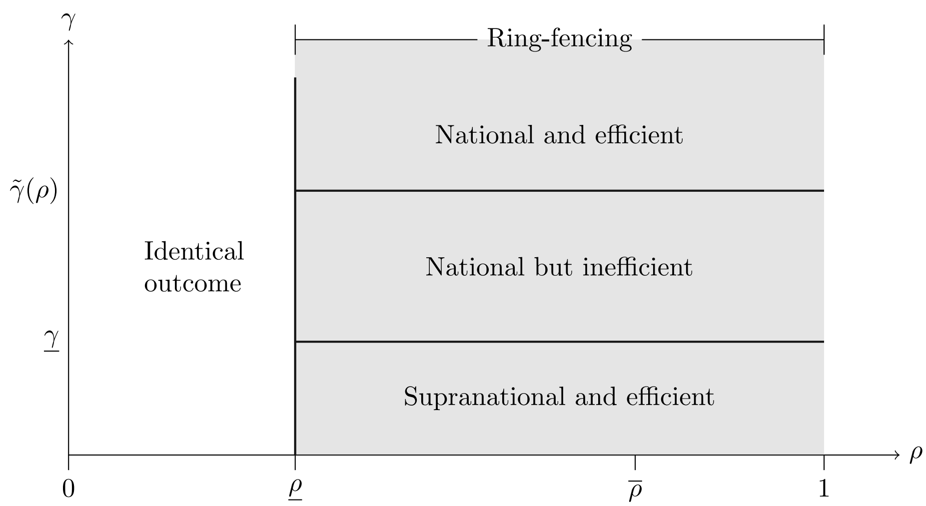

Figure 7: The institutional architecture that is incentive compatible and whether it is efficient.

Corollary 1. *Let $\underline{\rho}, \underline{\gamma}, \tilde{\gamma}(\rho)$ be the thresholds defined in Proposition 1, 2,and 6, respectively. For $\gamma \in (\underline{\gamma}, \tilde{\gamma}(\rho)]$ and $\rho > \underline{\rho}$ a supranational architecture increases both welfare and national deposit insurance costs relative to a national architecture. For any other parameter values, the architecture that maximizes welfare also minimizes deposit insurance costs.*

This result states that, for banks with intermediate fundamentals ($\gamma \in (\underline{\gamma}, \tilde{\gamma}(\rho)]$) and high correlation between its units' final payoffs ($\rho > \underline{\rho}$), a supranational architecture is welfare improving, although national authorities, aiming to protect their deposit insurance funds, prefer a national architecture. As discussed before, this is because the latter provides national authorities with ring-fencing prerogatives that provides a disciplining effect and encourages bank effort for these banks, albeit at the cost of less efficient intervention in the impaired units.

4 Implications

Our model yields novel empirical predictions on the emergence of ring-fencing under a national architecture, on the effects of moving from a national to a supranational architecture, and on the likelihood that national authorities delegate supervisory power to a supranational authority. Our model derives these implications based on variations in the parameters γ and

ρ. Recall that γ is a measure of a CBB's fundamental default risk. This can be related to the bank's asset quality and/or capitalization level. Instead, the parameter ρ measures the extent to which payoffs of a CBB's assets are correlated between subsidiaries located in different countries. A country pair can have a higher correlation when they are more integrated either economically (due to, e.g. international trade exposures) or financially (due to direct bank holdings of foreign assets or indirect exposure via international interbank relationship).

Implication 1: Under a national architecture, the emergence of ring-fencing leads the CBB to recapitalize its impaired unit via voluntary support that is partially financed with external equity issuance by the healthy unit. This result follows from Proposition 1. The novelty of this result lies in that the external financing for the recapitalization of the distressed unit is obtained by the healthy unit, not by the distressed unit. This arrangement minimizes the amount of external financing needed to recapitalize the distressed unit by minimizing the conflict of interest between the supervisory authority of the distressed unit and the bank. This is because the intra-group loan gives the healthy unit's depositors priority over the distressed unit's cash flows, while the external investors are only receiving the junior tranche of the distressed unit's cash flow. According to the report on intra-group support measures conducted by The Joint Forum (2012), the majority of respondents surveyed indicated centralised capital systems were in place.

Implication 2: Ring-fencing under a national architecture is more severe for CBBs that operate in countries with higher economic and financial integration. This prediction follows directly from Proposition 1. As the correlation between the (final) payoffs of the assets in the two given banking units increases it becomes less likely that the repayment of an intragroup loan benefits the supervisory authority of the healthy unit while the cost of providing such loan to it remains unchanged. Thus, the supervisory authority of a healthy unit is more likely to put restrictions on intragroup loans made to an impaired subsidiary. This implication highlights the tension between the increasing cross-border integration of the financial markets and a regulatory architecture under which bank distress is solved along national borders. The above mentioned report by The Joint Forum (2012) corroborates the presence of regulatory restrictions that limit the extent to which support can be extended.

Implication 3: Following the establishment of a supranational architecture, supervisory *intervention is more likely to result in recapitalization of distressed units as opposed to liquidation. The effect is more pronounced for countries with higher economic and financial integration.* Our analysis (Propositions 1 and 3) has demonstrated that moving to a supranational architecture eliminates ring-fencing and facilitates the efficient recapitalization of distressed units through voluntary support. This prediction is well in line with the outcomes of the Vienna Initiative 1 and 2, which are good example of supervisory cooperation. The Vienna Initiative 1 and 2 brought together all the relevant public and private sector stakeholders of EU-based cross-border banks present in Central and Eastern Europe and resulted in Western-European banks not abandoning their subsidiaries during the 2008 financial crisis and during 2011 sovereign debt crisis. Indeed, De Haas et al. (2015) provide evidence that subsidiaries of foreign banks in countries that were part of the Vienna Initiative remained stable lenders during the financial criss while those that were not sharply curtailed credit.

Implication 4: Following the establishment of a supranational architecture, the default probability of riskier cross-border banks decreases while that of safer cross-border banks increases, thereby leading to a risk convergence across cross-border banks. The effect is more pronounced for countries with higher economic and financial integration. We show that supervisory architecture also influences a CBB's behaviour ahead of financial distress by influencing the banks' effort choices (Propositions 2 and 4). Fiordelisi et al. (2017) find that the Single Supvisory Mechanism (SSM) led (affected) European banks to rebalance their portfolios towards safer assets on average. Our model suggests extensions to their work in two directions. First, to test our model, the analysis should be conducted at the banking unit level, not at the banking group level. Second, the average impact of the SSM can hide important cross-sectional heterogeneity which can be explained by country characteristics, so that one should interact the SSM "treatment" with such characteristics, or consider country pairs.

Implication 5: A supranational architecture will more likely emerge between countries with higher economic and financial integration. This result follows from Proposition 5, which shows that national authorities benefit from delegating supervision decisions to a supranational authority when ring-fencing is severe under a national architecture (high ρ). While in our model this takes the form of a single supervisory authority, there are more limited types of cooperation, such as agreements on information sharing or joint exercises on crisis prevention and resolution. Beck et al. (2018) construct bank-specific supervisory cooperation indices that measure the degree to which a CBB's parent-subsidiary structure is covered by cross-border supervisory cooperation agreements and find that it is increasing in proxies for integration.

Implication 6: A supranational architecture will more likely emerge between countries in which banking assets inherently have higher default risk. Proposition 5 also shows that national authorities benefit from delegating supervision decisions to a supranational authority when the incentive effect of eliminating ring-fencing is positive (low γ). Indeed, Beck et al. (2018) find that when countries decide to set up supervisory cooperation financial stability improves through reduced risks in banking assets. Our model also suggests that the benefits of supervisory cooperation should be felt in banking units with lower quality banking assets. Thus our model suggests to interact bank characteristics with the proxies for integration to analyze the effect on supervisory cooperation.

5 Conclusion

Intragroup transfers within a cross-border bank can be part of efficient central liquidity and capital management. However, repeated instances of ring-fencing imposed by national authorities to restrict intragroup transactions have raised concerns the negative consequences ring-fencing may have on financial stability. In this paper, we model the supervisory intervention of an impaired unit of a cross-border bank, and analyze under different institutional architectures the possibility of cross-unit voluntary support and supervisory ring-fencing.

The model allows us to understand the emergence of ring-fencing practices and their welfare consequences. We show that ring-fencing can arise under a national architecture for high correlation between the subsidiaries assets, and when that happens there is some value destruction. A supranational architecture eliminates ring-fencing, but can improve or reduce the cross-border bank's effort incentives depending on its risk profile. Our analysis also sheds light on the scenarios in which the establishment of a supranational authority for the supervision of a multinational bank is compatible with the objectives of national authorities to minimize their domestic expected deposit insurance costs, and on the cases in which those interests may conflict with overall welfare maximization.

Appendix

Proof of Proposition 1. Let us define $\underline{\rho}$ as the solution to

$$(1-p_h)\frac{L-p_\ell(1-r)}{1-p_\ell} - (1-\rho)p_\ell(R+r+\frac{L-p_\ell(1-r)}{1-p_\ell}-1) = (1-p_h)(1-r). \qquad (16)$$

$\underline{\rho} \in (p_h, 1)$ exists and is unique, because the left-hand side of (16) is strictly small than the right-hand side for $\rho = p_h$ by Assumption 3, is strictly greater than the right-hand side for $\rho = 1$, and is strictly increasing in ρ.

We proceed in two steps. We first solve for the banker's optimal recapitalization plan that ensures the continuation of both units. We then compare the banker's expected payoff under such recapitalization plan to that without recapitalization, in order to derive the conditions for which the banker prefers not to recapitalize.

The banker's optimal recapitalization plan that ensures the continuation of both units. Notice that, as stated in Footnotes 14 and 15, the expressions for $C_1^B(x^B, s)$ and $C_1^A(x^A, s, S \mid \rho)$ in (3) and (4) assume that $r + x^B + s \leq 1$ and $r + x^A - s + S \leq 1$. Without imposing these assumptions, the two authorities' approval requirements are given by:

$$C_1^B(x^B, s) = (1-p_\ell)\left[1-(r+x^B+s)\right]^+ \leq 1-L, \qquad (17)$$

$$C_1^A(x^A, s, S \mid \rho) = (1-\rho)p_\ell\left[1-(r+x^A-s)-S\right]^+ + \left[1-p_h-(1-\rho)p_\ell\right]\left[1-(r+x^A-s)\right]^+ \leq (1-p_h)(1-r). \qquad (18)$$

The banker's optimization problem is to maximize his expected payoff as of $t = 1$, which is given by (6), subject to the two authorities' approval requirements given by (17) and (18), the non-negativity constraint $x^A, x^B \geq 0$, and the budget constraint given by (2).

To solve this optimization problem, we starting by showing that any solution that does not satisfy $r + x^B + s \leq 1$ and $r + x^A - s + S \leq 1$ is not optimal. Suppose first that $r + x^B + s > 1$, which implies that constraint (17) is slack, and that $x^B + s > 0$ as $r < 1$. It is therefore positive to decrease $x^B + s$ by decreasing either x^B or s by ϵ, whichever is strictly positive. We now construct profitable deviations in the following two cases.

- If the budget constraint (2) is slack, then for ϵ sufficiently small, decreasing $x^B + s$ strictly increases the bank's expected payoff while keeping all constraints satisfied.

- If the budget constraint (2) binds, which implies that $S > 0$, then for ϵ sufficiently small, decreasing both $x^B + s$ and S by ϵ while increasing x^A by $\mathbb{1}_{1-(r+x^A-s)-S>0}(1-p_h)$ strictly increases the bank's expected payoff while keeping all constraints satisfied.

Suppose next that $r + x^A - s + S > 1$. Then without loss of generality, we can decrease S until $r + x^A - s + S = 1$.

We now replace constraints (17) and (18) with (3) and (4), and show that the solution to this alternative optimization problem indeed satisfies $r + x^B + s \leq 1$ and $r + x^A - s + S \leq 1$. We solve this alternative problem in two steps. We first drop the budget constraint given by (2), and show that the solution to this simplified problem indeed satisfies (2) and therefore is the solution to the full problem if and only if $\rho \leq \underline{\rho}$. We then impose a binding budget constraint (2) and solve for the solution to this problem for $\rho > \underline{\rho}$.

(i) Consider the simplified problem given by the objective function (6), the constraints (3)–(4) and the non-negativity constraint $x^A, x^B \geq 0$. Let us denote the Lagrangian multipliers on the approval requirements of authority B and A in (3) and (4), respectively, by μ^i for $i \in \{A, B\}$, and that on the non-negativity constraints on x^i by ξ^i for $i \in \{A, B\}$. We derive the following first order conditions with respect to x^A, x^B, s, and S, respectively:

$$-(1-p_h)(1-\mu^A) - c + \xi^A = 0, \tag{19}$$

$$-(1-p_\ell)(1-\mu^B) - c + \xi^B = 0, \tag{20}$$

$$(1-p_h)(1-\mu^A) - (1-p_\ell)(1-\mu^B) = 0, \tag{21}$$

$$-(1-\rho)p_\ell(1-\mu^A) = 0, \tag{22}$$

and their respective complementary slackness conditions. We can now characterize the solution to this simplified optimization problem. (22) implies that $\mu^A = 1$ and therefore the constraint (4) binds by complementary slackness. $\mu^A = 1$ and (19) imply that $\xi^A = c$ and therefore $x_A = 0$ by complementary slackness. (21) implies that $\mu^B = \mu^A = 1$ and therefore (3) binds by complementary slackness. $\mu^B = 1$ and (20) imply that $\xi^A = c$ and therefore $x^B = 0$ by complementary slackness. Imposing $x^A = x^B = 0$, a binding constraint (3) implies that $s = \frac{L-p_\ell(1-r)}{1-p_\ell}$, and a binding constraint (4) in turn implies that $S = \frac{1-p_h}{(1-\rho)p_\ell}\frac{L-p_\ell(1-r)}{1-p_\ell}$. Notice that this solution satisfies the budget constraint (2) if and only if $\rho \leq \underline{\rho}$, where $\underline{\rho}$ is defined as the solution to (16). It is therefore also the solution to the alternative optimization problem defined above for $\rho \leq \underline{\rho}$.

(ii) Consider next the simplified problem given by the objective function (6), the constraints (3)–(4) and the non-negativity constraint $x^A, x^B \geq 0$, subject to a binding budget constraint (2) for $\rho > \underline{\rho}$. After substituting the binding budget constraint (2) into the objective function and the remaining constraints to eliminate S, we derive the following first order conditions with respect to x^A, x^B and s, respectively:

$$-(1-p_h)(1-\mu^A) - c + \xi^A = 0, \tag{23}$$

$$-(1-p_\ell)(1-\mu^B) - c + \xi^B = 0, \tag{24}$$

$$[(1-p_h) - (1-\rho)p_\ell](1-\mu^A) - (1-p_\ell)(1-\mu^B) = 0, \tag{25}$$

and their respective complementary slackness conditions, where the Lagrangian multipliers are similarly as defined above. (25) implies that either $\mu^A, \mu^B \leq 1$, or $\mu^A, \mu^B > 1$. We consider these to cases separately.

- Suppose $\mu^A, \mu^B \leq 1$. Then (23)–(24) imply $\xi^A, \xi^B > 0$ and therefore $x^A = x^B = 0$ by complementary slackness. (25) implies that either $\mu^B = \mu^A = 1$, or $\mu^B > \mu^A \geq 0$. In either case, $\mu^B > 0$ and therefore constraint (3) binds by complementary slackness. $x^B = 0$ and a binding constraint (3) then imply $s = \frac{L-p_\ell(1-r)}{1-p_\ell}$, the same as in Case (i). However, the analysis in Case (i) shows that S that binds the constraint (4) violates the budget constraint (2) for $\rho > \underline{\rho}$. However, since lowering S tightens the constraint (4), there exists no S that satisfies both the constraint (4) and the budget constraint (2) for $\rho > \underline{\rho}$.
- Suppose $\mu^A, \mu^B > 1$. This implies that the constraints (3) and (4) bind by complementary slackness. Moreover, (25) implies that $(1-p_h)(1-\mu^A) < (1-p_\ell)(1-\mu^B)$, and therefore (23)–(24) imply that $\xi^B > \xi^A \geq 0$. $\xi^B > 0$ implies that $x_B = 0$ by complementary slackness. Imposing $x_B = 0$, a binding constraint (3) implies that $s = \frac{L-p_\ell(1-r)}{1-p_\ell}$, and a binding constraint (4) in turn implies that $x^A =$

$\frac{L-p_\ell(1-r)}{1-p_\ell} - \frac{(1-\rho)p_\ell}{1-p_h}(R + r + \frac{L-p_\ell(1-r)}{1-p_\ell} - 1).$

To summarize, the solution to the alternative optimization problem defined by the objective function (6), constraints (3)–(4), the non-negativity constraint $x^A, x^B \geq 0$, and the budget constraint (2) is

$$
\begin{aligned}
x^A &= x_h^*(\rho) \equiv \begin{cases} 0, & \text{if } \rho \leq \underline{\rho}, \\ s^* - \frac{(1-\rho)p_\ell}{1-p_h}(R + r + s^* - 1), & \text{if } \rho > \underline{\rho}, \end{cases} \\
x^B &= 0, \\
s &= s^* \equiv \frac{L - p_\ell(1-r)}{1-p_\ell}, \\
S &= S^*(\rho) \equiv \begin{cases} \frac{1-p_h}{(1-\rho)p_\ell}s^*, & \text{if } \rho \leq \underline{\rho}, \\ R + r + s^* - 1, & \text{if } \rho > \underline{\rho}. \end{cases}
\end{aligned} \tag{26}
$$

Recall that, as stated in Footnote 13, we have omitted the budget constraint $s \leq r + x^A$. This is indeed satisfied at the above solution, because part (i) of Assumption 4 implies that $s^* = \frac{L-p_\ell(1-r)}{1-p_\ell} < r$.

It is straightforward to verify that this solution satisfies $x^B + s \leq 1$ and $r + x^A - s + S \leq 1$. To see this, first, we have $x^B + s = s^* < r < 1$. Second, for $\rho \leq \underline{\rho}$, we have $r + x^A - s + S \leq r + x^A - s + R + (r + x^B + s) - 1 = R + r - 1 < 1$, where the first inequality follows from the budget constraint given by (2), and the last inequality follows from Assumption 1. (iii) For $\rho > \underline{\rho}$, we have $r + x^A - s + S = r + \frac{(1-p_h)-(1-\rho)p_\ell}{1-p_h}(R + s^* - 1) \leq R + r + s^* - 1 < 1$, where the last inequality follows from Assumption 1 and the fact that $s^* < r$.

Therefore the solution given by (26) characterizes the banker's optimal recapitalization plan that ensures the continuation of both units.

The banker's decision to recapitalize. The banker prefers not to recapitalize the bank if and only if the expected payoff difference given by (7) is negative, when evaluated at the banker's optimal recapitalization plan that ensures the continuation of both units given by (26). Using the fact that, this recapitalization plan binds the constraints (3) and (4), and that $x^A = x_h^*(\rho)$ and $x^B = 0$, (7) evaluated at the solution given by (26) is equal to

$$\Pi_1(x_h^*(\rho), 0, s^*, S^*(\rho)) - \underline{\Pi}_1 = (p_\ell R - L) - x_h^*(\rho)c. \tag{27}$$

Recall that $x_h^*(\rho) > 0$ if and only if $\rho > \underline{\rho}$ as shown previously, and that in this case, $x_h^*(\rho) = s^* - \frac{(1-\rho)p_\ell}{1-p_h}(R + r + s^* - 1)$. Since $x_h^*(\rho)$ is strictly increasing in ρ, there exists a unique threshold $\overline{\rho}$, such that the banker recapitalizes the bank if and only if $\rho \leq \overline{\rho}$, where $\overline{\rho}$ is defined as the solution to $(p_\ell R - L) - x_h^*(\rho)c = 0$, or

$$(p_\ell R - L) - \left(\frac{L - p_\ell(1-r)}{1-p_\ell} - \frac{(1-\overline{\rho})p_\ell}{1-p_h}(R + r + \frac{L - p_\ell(1-r)}{1-p_\ell} - 1)\right) c = 0. \tag{28}$$

Finally, notice that $\overline{\rho} \in (\underline{\rho}, 1)$, because the left-hand side of the above expression (i) is strictly decreasing in ρ, (ii) is strictly positive for $\overline{\rho} = \underline{\rho}$, in which case the second term in the above expression is equal to zero, and (iii) is strictly negative for $\overline{\rho} = 1$ by Assumption 4. □

Proof of Proposition 2. The equilibrium effort is characterized by the first order condition given by (9) for all $i, j \in \{A, B\}$ and $i \neq j$. Let $\hat{e}_i(e_j)$ denote the solution to (9). Assumption 2 implies that a unique solution $\hat{e}^i(e^j) \in (0, 1-\gamma)$ exists, which is decreasing in e_j, for all $i, j \in \{A, B\}$ and $i \neq j$. The equilibrium can thus be characterized by the solution to the following fixed point problem for all $i, j \in \{A, B\}$ and $i \neq j$:

$$\hat{e}^i(\hat{e}^j(e^i)) = e^i. \tag{29}$$

Notice that the left-hand side of (29) is strictly greater than the right-hand side for $e^i = 0$, strictly less than the right-hand side for $e_i = 1$. Moreover, we have

$$\frac{\partial \hat{e}^i(\hat{e}^j(e^i))}{\partial e^i} = \frac{\partial \hat{e}^i(e^{j*})}{\partial e^j}\frac{\partial \hat{e}^j(e^{i*})}{\partial e^i} = \frac{\left(2\left[(p_\ell R - L) - x_h^*(\rho)c\right]^+\right)^2}{k''(e^{i*})k''(e^{j*})} < 1, \tag{30}$$

where the inequality follows from Assumption 2. Therefore a fixed point exists and is unique, which characterizes the banker's optimal choice of e^i for all $i \in \{A, B\}$.

We have thus far established that the unique and symmetric solution to the banker's optimal effort choice exists. The solution, which we denote by $e^*(\rho, \gamma)$, is therefore characterized by

$$k'(e^*(\rho, \gamma)) = p_h(R + r - 1) + [1 - 2(\gamma + e^*(\rho, \gamma))]\left[(p_\ell R - L) - x_h^*(\rho)c\right]^+. \tag{31}$$

In particular, for $\rho \leq \underline{\rho}$, $x_h^*(\rho) = 0$ by Proposition 1, and we have $e^*(\rho, \gamma) = e^{**}(\gamma)$ for all γ, where $e^{**}(\gamma)$ is defined in (10).

The properties of $x^*(\rho,\gamma)$ stated in this proposition then follows. First, $e^*(\rho,\gamma)$ is strictly decreasing in γ for $\rho < \overline{\rho}$ and constant in γ for $\rho \geq \overline{\rho}$:

$$\frac{\partial e^*(\rho,\gamma)}{\partial \gamma} = \begin{cases} \frac{-2\left[(p_\ell R - L) - x_h^*(\rho)c\right]}{2\left[(p_\ell R-L)-x_h^*(\rho)c\right]+k''(e^*(\rho,\gamma))} \in (-1,0), & \text{if } \rho < \overline{\rho}, \\ 0, & \text{otherwise.} \end{cases} \tag{32}$$

Second, we have

$$\frac{\partial e^*(\rho,\gamma)}{\partial \rho} = \begin{cases} 0, & \text{if } \rho \leq \underline{\rho}, \\ \frac{-[1-2(\gamma+e^*(\rho,\gamma)]\frac{\partial x_h^*(\rho)}{\partial \rho}c}{2\left[(p_\ell R-L)-x_h^*(\rho)c\right]+k''(e^*(\rho,\gamma))}, & \text{if } \rho \in (\underline{\rho},\overline{\rho}), \\ 0, & \text{otherwise.} \end{cases} \tag{33}$$

where $\frac{\partial x_h^*(\rho)}{\partial \rho} > 0$ for $\rho \in (\underline{\rho},\overline{\rho})$ and $\frac{\partial x_h^*(\rho)}{\partial \rho} = 0$ otherwise by Proposition 1. Notice that (32) implies that $\gamma + e^*(\rho,\gamma)$ is strictly increasing in γ, so that there exists $\underline{\gamma}$ such that $\gamma + e^*(\rho,\gamma) \geq \frac{1}{2}$ if and only if $\gamma \geq \underline{\gamma}$, where $\underline{\gamma}$ is defined by

$$k'(\frac{1}{2} - \underline{\gamma}) = p_h(R + r - 1). \tag{34}$$

It then follows from (33) that, if $\gamma \leq \underline{\gamma}$, $e^*(\rho,\gamma) \leq e^{**}$ for $\rho > \underline{\rho}$ and $e^*(\rho,\gamma)$ is decreasing in ρ; if $\gamma \geq \underline{\gamma}$, $e^*(\rho,\gamma) \geq e^{**}$ for $\rho > \underline{\rho}$ and $e^*(\rho,\gamma)$ is increasing in ρ. □

Proof of Proposition 3. Let us consider the banker's optimal recapitalization plan that ensures the continuation of both units. The banker's optimization problem maximizes the banker's expected payoff given in (6), subject to the supranational authority's minimum capital requirement (11), the non-negativity constraints $x^A, x^B \geq 0$, and the budget constraint (2).

Notice that the recapitalization plan given in Proposition 1 satisfies the budget constraint (2), satisfies the constraint (2) with equality, and has $x^A = x^B = 0$. The existence of such a recapitalization plan implies that, first, since any optimal recapitalization plan that ensures the continuation of both units leaves to a weakly higher expected payoff for the banker, any such recapitalization binds (11) and has $x^A = x^B = 0$. Second, it implies that the banker always finds it optimal to recapitalize the bank.

We can now characterize the bank's optimal recapitalization plan, which satisfies $x^A = x^B = 0$, the budget constraint (2), and binds (11). After imposing $x^A = x^B = 0$, a binding constraint (11) can be expressed as follows, using the expressions for $C_1^B(x^B, s)$ and

$C_1^A(x^A, s, S \mid \rho)$ given by (3) and (4), respectively:

$$(1-p_\ell)(1-s) + (1-\rho)p_\ell(1-r+s-S)^+ + [1-p_h-(1-\rho)p_\ell](1-r+s) \\ = (1-L-r) + (1-p_h)(1-r). \qquad (35)$$

Notice that in the above expression, we have used the fact that $s < r < 1$, where the first inequality follows from the budget constraint discussed in Footnote 13 and $x^A = 0$. This implies that $1-s > 0$ and $1-r+s > 0$.

Since there exist a continuum of (s, S) that satisfy (35), we now solve for the pair (s, S) that minimizes the redistribution between the two countries' deposit insurance funds. Consider the following two cases.

- $\rho \le \underline{\rho}$. In this case, it is easy to verify that $s^* = \frac{L-p_\ell}{1-p_\ell}$ and $S^*(\rho) = \frac{1-p_h}{(1-\rho)p_\ell}s^*$ satisfy (35). Moreover, since it does not lead to any redistribution, i.e. (3) and (4) are both satisfied with equality, this is also the recapitalization plan that minimizes redistribution between the two countries' deposit insurance funds.

- $\rho > \underline{\rho}$. In this case, (35) and $S \le R + r + s - 1$ imply that

$$s \ge s^{**}(\rho) \equiv \frac{L - p_\ell - (1-\rho)p_\ell(R-1)}{p_h - \rho p_\ell} > s^*, \qquad (36)$$

  where the last inequality follows from $\rho > \underline{\rho}$. For all $s > s^*$, and S that satisfies (35), the expected cost to the deposit insurance fund of country B is strictly decreasing and that of country A is strictly increasing in s. Therefore, the recapitalization plan that minimizes redistribution between the two countries' deposit insurance funds has $s = s^{**}(\rho)$ and $S = S^{**}(\rho) \equiv R + r + s^{**}(\rho) - 1$.

□

Proof of Proposition 4. The first order condition that characterizes the banker's optimal risk choice under a supranational architecture coincides with that under a national architecture for $\rho \le \underline{\rho}$. Therefore it is equal to $e^{**}(\gamma)$ for each unit, where $e^{**}(\gamma)$ is defined by (10). □

Proof of Proposition 5. This result follows immediately from the observation that $C_0(e)$ is increasing in e, and the properties of $e^*(\rho, \gamma)$ and $e^{**}(\rho)$ described in Propositions 2 and 4. □

Proof of Proposition 6. For $\rho \leq \underline{\rho}$, we have $W(e^{**}(\gamma);0) = W(e^*(\rho,\gamma);x_h^*(\rho))$ because $e^{**}(\gamma) = e^*(\rho,\gamma)$ and $x_h^*(\rho) = 0$ by Propositions 1–4.

For $\rho > \underline{\rho}$, let us rewrite the welfare difference as follows:

$$\begin{aligned} & W(e^{**}(\gamma);0) - W(e^*(\rho,\gamma);x_h^*) \\ = \; & [\Pi_0(e^{**}(\gamma), e^{**}(\gamma);0) - \Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma);x_h^*(\rho))] - 2\,[C_0(e^{**}(\gamma)) - C_0(e^*(\rho,\gamma))]\,. \end{aligned} \tag{37}$$

If $\gamma \leq \underline{\gamma}$, (37) is strictly positive, because the first term is positive by (15), and the second term is negative by Proposition 5.

For $\rho > \underline{\rho}$ and $\gamma > \underline{\gamma}$, we will show that the welfare difference $W(e^{**}(\gamma);0) - W(e^*(\rho,\gamma);x_h^*)$ is strictly decreasing in γ. To see this, consider first the difference in the expected deposit insurance cost:

$$C(e^{**}(\rho)) - C(e^*(\rho,\gamma)) = [e^{**}(\gamma) - e^*(\rho,\gamma)]\,[L - p_h(1-r)]\,, \tag{38}$$

$$\frac{\partial C(e^{**}(\rho)) - C(e^*(\rho,\gamma))}{\partial\gamma} = \left[\frac{\partial e^{**}(\gamma)}{\partial\gamma} - \frac{\partial e^*(\rho,\gamma)}{\partial\gamma}\right][L - p_h(1-r)] > 0. \tag{39}$$

Recall that $\frac{\partial e^*(\rho,\gamma)}{\partial\gamma}$ is given by (32), and from (31), we have

$$\frac{\partial e^{**}(\gamma)}{\partial\gamma} = -\frac{2(p_\ell R - L)}{2(p_\ell R - L) + k''(e^{**}(\gamma))} \in (-1, 0). \tag{40}$$

Since we have $e^{**}(\gamma) < e^*(\rho,\gamma)$ and $x_h^*(\rho) > 0$ for all $\rho > \underline{\rho}$, we have that $k''(e^{**}(\gamma)) < k''(e^{**}(\gamma))$ by Assumption 2 and thus $\frac{\partial e^{**}(\gamma)}{\partial\gamma} < \frac{\partial e^*(\rho,\gamma)}{\partial\gamma}$ by comparing (32) and (40). It then follows that the $\frac{\partial C(e^{**}(\rho)) - C(e^*(\rho,\gamma))}{\partial\gamma} > 0$, because $L - p_h(1-r) < 0$ by Assumption 3.

We analyze next the difference in the banker's expected profit.

$$\begin{aligned} & \frac{d\Pi_0(e^{**}(\gamma), e^{**}(\gamma);0) - \Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma);x_h^*(\rho))}{d\gamma} \\ = \; & 2\,[1 - 2(\gamma + e^{**}(\gamma))]\,(p_\ell R - L) - 2\,[1 - 2(\gamma + e^*(\rho,\gamma))]\,[(p_\ell R - L) - x_h^*(\rho)c]\,, \end{aligned} \tag{41}$$

which, by the envelop theorem, contains only the direct effect of changes in γ, and no indirect effects through the changes in the the effort choice. Notice that, at $\rho \to \underline{\rho}$, we have $\frac{d\Pi_0(e^{**}(\gamma), e^{**}(\gamma);0) - \Pi_0(e^*(\rho,\gamma), e^*(\rho,\gamma);x_h^*(\rho))}{d\gamma} = 0$, because $e^{**}(\gamma) = e^*(\underline{\rho},\gamma)$ and $x_h^*(\underline{\rho}) = 0$. Moreover, we have,

$$\frac{d^2\Pi_0(e^{**}(\gamma),e^{**}(\gamma);0)-\Pi_0(e^*(\rho,\gamma),e^*(\rho,\gamma);x_h^*(\rho))}{d\gamma d\rho}$$

$$=4\frac{\partial e^*(\rho,\gamma)}{\partial\rho}\left[(p_\ell R-L)-x_h^*(\rho)c\right]+2\left[1-2(\gamma+e^*(\rho,\gamma))\right]\frac{\partial x_h^*(\rho)}{\partial\rho}c \tag{42}$$

$$=\begin{cases}2\left[1-2(\gamma+e^*(\rho,\gamma))\right]\left(-\frac{2\left[(p_\ell R-L)-x_h^*(\rho)c\right]}{2\left[(p_\ell R-L)-x_h^*(\rho)c\right]+k''(e^*(\rho,\gamma))}+1\right)\frac{\partial x_h^*(\rho)}{\partial\rho}c<0, & \text{if } \rho\in(\underline{\rho},\overline{\rho}),\\ 0, & \text{if } \rho\geq\overline{\rho}.\end{cases} \tag{43}$$

where the inequality follows from the fact that $\frac{\partial e^*(\rho,\gamma)}{\partial\rho}<0$ for $\rho\in(\underline{\rho},\bar{\rho})$ by (33). This then implies that that we have $\frac{d\Pi_0(e^{**}(\gamma),e^{**}(\gamma);0)-\Pi_0(e^*(\rho,\gamma),e^*(\rho,\gamma);x_h^*(\rho))}{d\gamma}<0$ for all $\rho>\underline{\rho}$.

Overall, we thus have that the welfare difference $W(e^{**}(\gamma);0)-W(e^*(\rho,\gamma);x_h^*)$ is strictly decreasing in γ for all $\rho>\underline{\rho}$ and $\gamma>\underline{\gamma}$, because $\Pi_0(e^{**}(\gamma),e^{**}(\gamma);0)-\Pi_0(e^*(\rho,\gamma),e^*(\rho,\gamma);x_h^*(\rho))$ is decreasing in γ and $C(e^{**}(\rho))-C(e^*(\rho,\gamma))$ is increasing in γ as shown above. Since we have that $W(e^{**}(\gamma);0)-W(e^*(\rho,\gamma);x_h^*)$ is strictly positive at $\gamma=\underline{\gamma}$, it follows that there exists $\tilde{\gamma}(\rho)>\underline{\gamma}$, such that $W(e^{**}(\gamma);0)-W(e^*(\rho,\gamma);x_h^*)\geq 0$ if and only if $\gamma\leq\tilde{\gamma}(\rho)$. □

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