MULTINATIONAL BANKS AND FINANCIAL STABILITY*

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We study the scope for international cooperation in macroprudential policies. Multinational banks contribute to and are affected by fire sales in countries they operate in. National governments setting quantity regulations noncooperatively fail to achieve the globally efficient outcome, underregulating domestic banks and overregulating foreign banks. Surprisingly, noncooperative national governments using revenue-generating Pigouvian taxation can achieve the global optimum. Intuitively, this occurs because governments internalize the business value of foreign banks through the tax revenue collected. Our theory provides a unified framework to think about international bank regulations and yields concrete insights with the potential to improve on the current policy stance. *JEL Codes:* F42, G28, D62.

I. INTRODUCTION

The banking industry is multinational in its scope: banks that are headquartered in one country lend to, borrow from, and are owned by agents across country borders.[1] In the aftermath of the 2008 financial crisis, financial stability concerns from cross-border banking have motivated regulators to extend postcrisis macroprudential regulatory regimes—such as equity capital and liquidity requirements—to foreign banks operating domestically and to apply capital control measures—such as residency-based

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1. For example, more than 30% of global bank claims are on foreign counterparties as of 2019, with more than half of foreign claims being on the nonbank private sector. Bank for International Settlements (BIS) Consolidated Banking Statistics (CBS), among reporting countries.

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transaction taxes—to manage capital flows.[2] It has also led to concerns that uncoordinated financial regulation may not be efficient, motivating international cooperative regulatory regimes involving common regulatory standards (Basel III) and common supervision and resolution (European Banking Union, Single Point of Entry (SPOE) resolution).[3] Despite the prominence of these agreements and their attention in the policy world, there is relatively limited formal economic analysis studying the need for macroprudential cooperation in the presence of financial stability concerns from cross-border banking, or to guide policy makers in forming cooperative agreements.

The main contribution of this article is to show that in a setting with cross-border banking and country-level fire sales, noncooperative national governments that use Pigouvian taxation to regulate banks are able to achieve the globally efficient outcome, provided there are no monopoly rents at the country level, eliminating the need for international cooperation.[4] The key mechanism that leads to efficiency is that taxes on foreign banks generate revenues for the domestic government. Even though the domestic government puts no direct value on the welfare of foreigners, we show that revenue collection allows the domestic government to internalize both the benefits to foreign banks from domestic operations and the spillovers to foreign banks from the domestic fire sale. By contrast, if governments use revenue-neutral taxes, they fail to achieve the efficient outcome. We show in our main model that the outcome under revenue-neutral taxes is also achieved in a model with explicit quantity restrictions, motivating existing cooperative agreements that are designed around use of quantity restrictions. We discuss the robustness of our Pigouvian tax efficiency result in more general banking environments and its limitations.

2. For example, the Intermediate Holding Company requirement in the US applies prudential standards of The Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act) to foreign banks with large operations in the US.

3. See BIS (2010) for an overview of Basel III, ECB (2018) for an overview of the EU Single Supervisory Mechanism (SSM) responsible for common supervision, Financial Stability Board (2013) for a discussion of SPOE, and Tucker (2016) for a discussion of motivations for cooperation.

4. We frame our study in terms of banks, but it also applies to broader classes of financial intermediaries.

The article develops a simple three-period economic framework to study the regulation of cross-border banks in the presence of fire sales. Despite its simplicity, the model captures key features of the global banking industry and real economy, and we show that its insights extend to a more general environment. In our model, banks issue debt to finance domestic and cross-border investment at the initial date. Banks experience shocks to the value of their investment positions at the interim date and must then roll over or repay their initial debt. When faced with binding collateral constraints, banks are forced to liquidate part of their total investment portfolio prematurely. Banks choose which investments to liquidate and generate fire sales in the countries they sell assets in. Fire sales in a country affect all banks that invest and sell assets in that country, leading to cross-border spillovers. These fire sale spillovers, which are not internalized by banks, motivate the consideration of macroprudential regulation.

We begin our discussion in Section III by studying the problem of a global planner who sets regulatory policy for all banks. The policies adopted by this global planner provide an efficiency benchmark to which we can compare the policies adopted by national governments. We show that globally efficient regulation involves placing state-contingent "wedges" (or taxes) on bank asset liquidations in each country. There are two key properties of the global optimum. First, the magnitude of the state-contingent liquidation taxes are set to the total fire sale spillovers to domestic and foreign banks generated by asset liquidations. Second, there is equal regulatory treatment in that the same taxes are applied to all banks, regardless of their domicile.

We next introduce country-level governments, or "country planners," who design regulation for their respective countries in a noncooperative manner, in Section IV. In practice, countries have regulatory jurisdiction over all activities of domestic banks and over the domestic activities of foreign banks. This means that multiple countries have regulatory jurisdiction over the same bank. In the absence of cooperative agreements, national regulators will set macroprudential policies independently to maximize national welfare. Our framework captures this common agency problem and allows us to study whether country planners can achieve the globally efficient outcome without international cooperation.

Country planners are endowed with the same regulatory taxes that were available to the global planner. Our main results relate to the differentiation between outcomes under two different rules for remission of revenues collected from the taxes. First, we study revenue-neutral taxes, under which revenue collected from taxes on foreign banks is remitted lump-sum back to foreign banks. Second, we study revenue-generating taxes, under which revenue collected from foreign banks is instead remitted lump-sum to domestic banks. Both of these instruments in principle would allow planners in our model to implement the globally efficient allocation. We show in the Online Appendix that a game with explicit quantity restrictions achieves the same outcome as revenue-neutral taxes in our baseline model. We therefore refer to revenue-neutral taxes in our model as quantity restrictions. By contrast, we term revenue-generating taxes to be Pigouvian taxation.

We first show that if country planners use revenue-neutral taxes (quantity restrictions), they fail to achieve the globally efficient outcome without international cooperation. There are two key departures from global efficiency. First, taxes placed on asset liquidations by domestic banks are too small, accounting for domestic fire sale spillovers but not for foreign fire sale spillovers. Second, taxes on domestic liquidations by foreign banks are too large, ensuring that foreign banks do not contribute to domestic fire sales. The equivalent implementation using explicit quantity restrictions applies ceiling restrictions on liquidations that are too flexible for domestic banks and too strict for foreign banks. This noncooperative optimum motivates a cooperative agreement that increases regulation of domestic banks and ensures equal treatment of foreign banks and helps rationalize the broad architecture and goals of existing international cooperative arrangements.

The main and most surprising result of our article is that noncooperative national governments using revenue-generating taxes (Pigouvian taxation) can implement the globally efficient outcome, eliminating the need for cooperation. In particular, country planners set tax rates that coincide with globally optimal policy, up to a monopolistic revenue extraction distortion. When countries' monopoly power is zero due to sufficient substitutability, noncooperative Pigouvian taxation is globally efficient. The mobility of global banking assets and the presence of large offshore financial centers suggests that low monopoly revenues at the country level are a plausible description of the world.[5]

5. For example, see the work by Coppola et al. (2021) on global capital flows and tax havens.

In contrast to revenue-neutral taxes (quantity restrictions), use of revenue-generating taxes (Pigouvian taxation) results in efficiency precisely because of the motivation for the domestic planner to collect tax revenues. When combined with the standard motivation to correct domestic externalities, this motive to collect tax revenue leads to efficient outcomes.[6] The intuition is that a country planner is willing to allow foreign banks to engage in socially costly domestic activities because she can collect more tax revenue as a result. This aligns preferences between the domestic planner and foreign banks because in equilibrium, the marginal tax rates on foreign banks' domestic activities are equal to the marginal benefit to foreign banks of those activities. And since domestic fire sales reduce the marginal benefit to foreign banks of domestic activities, they also reduce tax revenue collection. With an incentive to generate tax revenue, domestic planners internalize not only the benefits derived by foreign banks from domestic activities but also the costs imposed on them by domestic fire sales. By contrast, because quantity regulation does not generate revenues, the domestic planner does not consider the welfare effects of regulation on the value of foreign banks, which accrues to foreigners.

The efficiency of noncooperative Pigouvian taxation has implications for macroprudential policies and capital controls. Although in practice macroprudential policies often take the form of quantity regulation rather than Pigouvian taxation, we speculate that this may have arisen in part due to a combination of perceived duality between these instruments and political obstacles to taxation. Our results suggest that adopting a (noncooperative) tax-based approach to bank regulation can potentially be an alternative to explicit cooperative agreements over quantity restrictions.

We next study the practical policy implications of our results. In our baseline model of Sections II–IV, planners achieve efficiency by using state-contingent taxes on ex post bank asset liquidations. However, in practice regulators generally use ex ante macroprudential tools, such as equity capital and liquidity requirements. For this reason, much of the prior literature and policy debate have focused on these instruments. In Section V, we use a variant of our baseline model to study four types of policies that are central to Basel III and the European Banking Union: regulation of debt and illiquid asset positions, liquidity

6. That is, in our model, efficiency results from the "double dividend" of Pigouvian taxes—they correct externalities and generate revenues (Tullock 1967).

regulation, regulation of cross-border bank resolution, and provision of fiscal backstops (or bailouts). In this environment, noncooperative national governments again fail to achieve efficiency under revenue-neutral taxes, and as in the baseline model, we show how the same outcome is achieved using explicit quantity restrictions. Conversely, noncooperative governments achieve the efficient outcome, absent monopoly rents, using revenue-generating (Pigouvian) taxes. Our results suggest concretely that noncooperative regulators may be able to improve efficiency by (i) using taxes on debt and illiquid assets, rather than equity capital or leverage requirements; (ii) using taxes on liquid asset holdings, rather than liquidity requirements such as the liquidity coverage ratio (LCR); (iii) charging banks a fee based on organizational structure (e.g., MPOE versus SPOE), rather than imposing orderly resolution requirements; and (iv) charging banks a fee based on expected fiscal support, for example, a deposit insurance premium.

Finally, we study the robustness and limitations of our main result. In Section VI, we show that our results extend to a broader class of externality problems featuring multinational banks (or agents). We present a general model of these externality problems. We characterize two classes of externalities: local and global. Local externalities, such as spillovers to the domestic economy or to a domestic deposit guarantee scheme, only affect domestic agents. Global externalities, such as fire sales or climate change, affect both domestic and foreign agents. The efficiency of noncooperative Pigouvian (revenue-generating) taxation extends to the class of local externalities, following the same logic as in the main model. By contrast, the efficiency of noncooperative Pigouvian taxation under global externalities depends on the precise nature of international spillovers. When a domestic externality spreads endogenously through cross-border activities, as with fire sales, Pigouvian taxation results in efficient outcomes. However, when an externality generates international spillovers even in the absence of cross-border activities, as with climate change, or spreads through agents who cannot be regulated,[7] Pigouvian taxation is not generally efficient.

7. This limitation is to agents who (technologically) cannot be regulated and not to agents who can be regulated but are unregulated in equilibrium. For example, a (price) spillover to a foreign firm from reduced credit availability would be internalized even though the equilibrium tax on that firm is zero if it does not itself contribute to externalities.

I.A. Related Literature

First, we relate to a large empirical literature on the determinants and properties of capital flows and cross-border banking, including home bias.[8] These empirical observations help motivate the assumptions underlying our baseline banking model.

Second, we relate to a large literature on macroprudential regulation and capital controls in domestic and small open economies,[9] and to a smaller literature on optimal regulatory cooperation in international banking and financial markets.[10] Gersbach, Haller, and Papageorgiou (2020) show in a two-country model that country regulators using a combination of capital requirements and a bank tax achieve the efficient outcome when foreign households can deposit and own equity in domestic banks and generate a domestic spillover to the domestic deposit guarantee scheme. However, they do not consider fire sales or broader classes of externality problems and do not have common agency. Caballero and Simsek (2018, 2020) show that fickle capital flows can be a valuable source of liquidity to distressed countries. National regulators neglect this benefit and ban capital inflows to mitigate domestic fire sales. Korinek (2017) provides a first welfare theorem in a model where country planners control domestic agents, who interact on global markets. The environment in which this welfare theorem holds does not allow for domestic

8. For example, Caballero, Farhi, and Gourinchas (2008); Mendoza, Quadrini, and Ríos-Rull (2009), Milesi-Ferretti and Tille (2011), Forbes and Warnock (2012), Broner et al. (2013), Niepmann (2015), Maggiori (2017), Davis and Van Wincoop (2018), De Marco, Macchiavelli, and Valchev (forthcoming), Shen (2021), and Maggiori, Neiman, and Schreger (2020). See Coeurdacier and Rey (2013) for a broader overview of the home bias literature.

9. For example, Caballero and Krishnamurthy (2001), Lorenzoni (2008), Farhi, Golosov, and Tsyvinski (2009), Bianchi and Mendoza (2010), Bianchi (2011, 2016), Stein (2012), Farhi and Werning (2016), Bianchi, Liu, and Mendoza (2016), Chari and Kehoe (2016), Korinek and Simsek (2016), Schmitt-Grohé and Uribe (2016), Bianchi and Mendoza (2018), and Dávila and Korinek (2018). See Erten, Korinek, and Ocampo (2021) for a survey of the capital controls literature.

10. Additional contributions include Acharya (2003), Dell'Ariccia and Marquez (2006), Morrison and White (2009), Beck, Todorov, and Wagner (2013), Niepmann and Schmidt-Eisenlohr (2013), Beck and Wagner (2016), Farhi and Werning (2017), Foarta (2018), Calzolari, Colliard, and Lóránth (2019), and Segura and Vicente (2019). See also the literature on principal-agent problems with common agency, for example, Bernheim and Whinston (1986) and Dixit, Grossman, and Helpman (1997). In common with much of the literature, we apply a Nash equilibrium concept rather than contractible contracts (as in Szentes 2015).

prices to appear in foreign constraints, as in our model, and does not feature common agency because regulators have no direct controls over foreign agents. Farhi and Tirole (2018) show that national regulators loosen bank supervision to dilute existing international creditors, motivating supranational supervision. Bolton and Oehmke (2019) study the trade-off between single- and multi-point-of-entry in bank resolution. Bengui (2014) and Kara (2016) consider regulatory cooperation when banks' operations are domestic but the asset resale market is global. Our main contribution to this literature is to show that in an environment with international spillovers from fire sales, national governments using Pigouvian taxation can achieve the global optimum even though they fail to do so using quantity regulation.

Differences between quantity regulations and Pigouvian taxes have long been recognized by multiple literatures. The key distinction in our article derives from the double dividend—taxes correct for externalities and generate revenues for the planner (Tullock 1967). The international trade literature has long recognized that quotas (quantities) and tariffs (taxes) can be dual in the sense of generating the same allocation, but a tariff allocates marginal surplus to the government, whereas a quota may instead allocate surplus to foreigners (Bhagwati 1965, 1968; Shibata 1968; Magee 1972).[11] This insight has implications for (political) lobbying for tariff revenues (Bhagwati and Srinivasan 1980; Cassing and Hillman 1985), uncertainty (Fishelson and Flatters 1975; Pelcovits 1976; Dasgupta and Stiglitz 1977), and regulatory evasion (Falvey 1978). In our model, the revenue from the Pigouvian tax allows country planners to internalize fire sale spillovers to foreign banks. Another perspective emphasizes that uncertainty over private benefits and social costs leads to a trade-off between quantity regulation and (revenue-neutral) linear Pigouvian taxation (Weitzman 1974; Perotti and Suarez 2011). Although our

11. For example, consider a foreign company with fixed marginal cost of 1 selling to domestic consumers with CES demand $c = \frac{1}{p^{\sigma}}$. With a per unit import tariff $\tau > 0$ on the consumer, we have producer price $p^* = \frac{\sigma}{\sigma-1} + \frac{1}{\sigma-1}\tau$, an after-tax consumer price $p = p^* + \tau$, consumption $c^* = \frac{1}{p^{\sigma}}$, and tariff revenue τc^* for the government. By contrast with an import quota $c \leqslant c^*$ on consumers, we have a producer price $p = p^* + \tau$, a consumer price p, and no revenue for the government. Hence the end price faced by consumers is the same in both cases, but the tariff allocates the revenues τc^* to the government, whereas the quota allocates the "revenues" τc^* to the firm.

model assumes full information, we discuss the potential effects of Weitzman's (1974) considerations after presenting our main result.

II. Model

We present our baseline model, which is our leading example of a cross-border banking environment. In Section VI, we consider a more general environment, and discuss the robustness and limitations of our main results.

There are three dates, $t = 0, 1, 2$. The world economy consists of a unit continuum of countries, indexed by $i \in [0, 1]$. All countries are small and of equal measure but are not necessarily symmetric or otherwise identical.

Each country is populated by a representative bank and a representative arbitrageur. Banks raise funds from global investors to finance investment in both their home country and in foreign countries. Arbitrageurs are second-best users of bank investment projects, and purchase bank investments that are liquidated prior to maturity. Arbitrageurs and global investors exist in our model to solve for the general-equilibrium prices that banks face, but are not the primary focus of the model. Accordingly, we make their decision problems as simple as possible.

A global state $s \in S$, with continuous density $f(s)$, is realized at date 1, at which point uncertainty resolves. It captures all shocks in the model, including global, regional, and country-level shocks.

II.A. Banks

Banks are risk neutral and do not discount the future. Banks only consume at date 2, with final consumption denoted by $c_i(s)$.

1. *Bank Activities.* Banks are able to undertake an investment project (or asset) in each country at date 0. Projects are illiquid and suffer a loss when liquidated (sold) prior to maturity. We denote by I_{ij} the (date 0) investment scale undertaken by country i banks in the country j project, with $I_i = \{I_{ij}\}_j$ denoting a bank's investment portfolio.[12] We assume that bank investment is home biased: domestic investment, $I_{ii} \in \mathbb{R}_+$, is a mass point,

12. Our results on Pigouvian efficiency generalize to the case where there are multiple investment goods in each country and fire sale discounts are interconnected across assets.

whereas foreign investment, $I_{ij} : [0, 1] \to \mathbb{R}_+$, is a density.[13] Home bias can arise in the model when domestic banks specialize in domestic activities. Because fire sales will be a core focus of the model, we use the assumption of home bias to ensure that domestic banks retain a substantial exposure to the domestic economy, creating a motivation for domestic regulation. Assuming that banks retain only a marginal exposure to foreign countries is a simplifying assumption to maintain tractability.[14]

Banks operate a technology at date 0 that uses $\Phi_{ij}(I_{ij})$ units of the numeraire to produce I_{ij}, where Φ_{ij} is increasing and weakly convex. Banks' total investment cost is therefore $\Phi_{ii}(I_{ii}) + \int_j \Phi_{ij}(I_{ij})dj$.

At date 1, all projects in country j experience a quality shock $R_j(s)$, transforming the scale of projects operated by country i banks in country j to $R_j(s)I_{ij}$. Projects do not yield dividends at date 1 but yield $1 + r_{ij} \geqslant 1$ units of the consumption good per unit of scale when held to maturity at date 2. Intuitively, $R_j(s)$ captures a common risk exposure and r_{ij} captures different specializations (comparative advantages) in bank lending.

Projects may be liquidated at date 1, prior to maturity. We denote project liquidations by L_i, defined analogously to I_i, with $0 \leqslant L_{ij}(s) \leqslant R_j(s)I_{ij}$. Liquidated projects are sold to arbitrageurs at price $\gamma_j(s) \leqslant 1$, with the final return r_{ij} being lost.[15]

2. *Bank Financing.* Banks finance investment using an initial endowment $A_i > 0$ and by issuing external debt D_i from risk-neutral global investors at price 1.[16] For expositional simplicity, we consolidate banks' balance sheets across countries and operations. Given a fixed debt price of 1, the liquidation prices γ are the only endogenous prices in the model. The bank uses its total funds to finance its investment portfolio at date 0,

13. See Caballero and Simsek (2020) for a similar assumption. As highlighted in the introduction, home bias is an empirical regularity.

14. In Online Appendix E.7, we study a game with a finite number of countries whose banks maintain large exposures in foreign countries.

15. For simplicity, we do not allow banks to purchase assets liquidated by other banks, which would bolster the liquidation price in cases where banks were not in correlated distress. In Section VI, we show that allowing banks to both purchase and sell assets does not alter our main Pigouvian efficiency result.

16. We assume that risk-neutral global investors have deep pockets, and therefore always finance debt at a price of 1.

so that the date 0 bank budget constraint is

$$\Phi_{ii}(I_{ii}) + \int_j \Phi_{ij}(I_{ij})dj \leqslant A_i + D_i. \tag{1}$$

At date 1, banks can roll over debt at a price of 1, meaning that D_i is also the amount of new debt that needs to be issued at date 1. Consolidating the dates 1 and 2 budget constraints yields

$$c_i(s) \leqslant \mathscr{R}_{ii}(s) + \int_j \mathscr{R}_{ij}(s)dj - D_i, \tag{2}$$

where $\mathscr{R}_{ij}(s) = \gamma_j(s)L_{ij}(s) + (1 + r_{ij})(R_j(s)I_{ij} - L_{ij}(s))$ is the total return to investment in country j for country i banks from both date 1 liquidations and date 2 final payoffs.

i. Collateral Constraint: Banks with no restrictions on debt rollover would never choose to liquidate assets, since liquidations always reduce bank value. To introduce a role for liquidations and fire sales, we impose a date 1 collateral constraint, which is a standard method of capturing forced deleveraging (e.g., Kiyotaki and Moore 1997). The date 1 collateral constraint requires banks to back debt issued at date 1 with collateral, and is given by

$$\begin{aligned} D_i \leqslant\ & \underbrace{\gamma_i(s)L_{ii}(s) + \int_j \gamma_j(s)L_{ij}(s)dj}_{\text{Funds from Liquidations}} \\ & + \underbrace{(1 - h_i(s))\mathscr{C}_{ii}(s) + \int_j (1 - h_j(s))\mathscr{C}_{ij}(s)dj}_{\text{Funds from Collateral}}, \end{aligned} \tag{3}$$

where $\mathscr{C}_{ij}(s) = \gamma_j(s)[R_j(s)I_{ij} - L_{ij}(s)]$ is the market value of collateral at date 1. The collateral haircut $h_j(s) \in [0, 1]$ reflects the extent to which investors discount a project's collateral value and can reflect economic (e.g., uncertainty) and political (e.g., expropriation) concerns about collateral quality. Banks that cannot roll over their entire liabilities using collateral must liquidate assets to repay investors.[17]

17. We can obtain similar qualitative results if the future price $1 + r_{ij}$ is used to value collateral (rather than the current price $\gamma_j(s)$), provided that in at least some countries haircuts are large enough that banks are forced to liquidate assets

3. *Bank Optimization.* At date 0, banks choose a contract (c_i, D_i, I_i, L_i) with commitment to maximize expected utility $\int_s c_i(s) f(s) ds$ subject to budget constraints (1) and (2), and the collateral constraint (3). Banks take equilibrium prices γ as given. We discuss the role of bank and planner commitment in Section IV.D.

II.B. Arbitrageurs and Liquidation Values

Country i arbitrageurs are second-best users of country i projects.[18] At date 1, they purchase an amount $L_i^A(s)$ of bank projects and convert them into the consumption good using an increasing and (weakly) concave technology $\mathscr{F}_i(L_i^A(s), s)$. Arbitrageur technology is inefficient in the sense that $\frac{\partial \mathscr{F}_i(L_i^A(s),s)}{\partial L_i^A(s)} \leqslant 1$, so that selling projects to arbitrageurs never results in a resource gain.

Arbitrageurs obtain surplus $c_i^A(s) = \mathscr{F}_i(L_i^A(s), s) - \gamma_i(s) L_i^A(s)$ from purchasing projects. Arbitrageurs are price takers, so that the equilibrium liquidation value is

$$\gamma_i(s) = \frac{\partial \mathscr{F}_i\left(L_i^A(s), s\right)}{\partial L_i^A(s)}, \quad L_i^A(s) = L_{ii}(s) + \int_j L_{ji}(s) dj, \tag{4}$$

where $L_i^A(s)$ is equal in equilibrium to total country i projects sold by all banks, including foreign ones. There is a fire sale spillover when additional liquidations reduce liquidation values, that is when the marginal product of bank projects in arbitrageur technology is strictly decreasing. The extent of the fire sale spillover reflects the ability of the economy to absorb liquidations by banks, with deeper fire sales arising when limited market depth allocates liquidated bank projects to increasingly less efficient users.

(that is, $(1 - h_j(s))(1 + r_{ij}) < \gamma_j(s)$). Quantitatively, the final term $(1 - h_j(s))[R_j(s) I_{ij} - L_{ij}(s)]$ in equation (9), which reflects revaluing of collateral, would drop out and tend to dampen the magnitude of regulation.

18. The empirical regularity of retrenchment by foreigners coinciding with domestic distress is suggestive of a role for local arbitrageurs (e.g., Broner et al. 2013). We discuss the possibility that banks also purchase assets in Section VI.D.

II.C. Motivations for Cross-Border Banking

To map our model into economically important applications, we characterize the motivations for cross-border banking in the competitive equilibrium of the model.[19]

The optimal liquidation rule $L_{ij}(s)$ is given by the first-order condition (FOC)

$$0 = \underbrace{\lambda_i^1(s)\big(\gamma_j(s) - (1 + r_{ij})\big)}_{\text{Resource Loss}} + \underbrace{\Lambda_i^1(s) h_j(s) \gamma_j(s)}_{\text{Collateral Haircut}} + \underline{\xi}_{ij}(s) - \overline{\xi}_{ij}(s), \tag{5}$$

where the (nonnegative) Lagrange multipliers are $\lambda_i^1(s)$ on the date 1 budget constraint (2), $\Lambda_i^1(s)$ on the date 1 collateral constraint (3), and $\underline{\xi}_{ij}(s), \overline{\xi}_{ij}(s)$ (respectively) on the constraints $0 \leqslant L_{ij}(s) \leqslant R_j(s) I_{ij}$ in state s. Equation (5) shows that because liquidations result in resource losses, that is, $(1 + r_{ij}) - \gamma_j(s) > 0$, banks only liquidate assets when the collateral constraint binds, that is, $\Lambda_i^1(s) > 0$. Banks prefer to liquidate assets with lower liquidation discounts, $(1 + r_{ij}) - \gamma_j(s)$, and higher collateral haircuts, $h_j(s)$.

The investment decision I_{ij} of banks is given by the first-order condition

$$0 \geq \overbrace{-\lambda_i^0 \frac{\partial \Phi_{ij}}{\partial I_{ij}} + E[\lambda_i^1] E\left[(1+r_{ij}) R_j\right]}^{\text{Specialization}} + \overbrace{\text{cov}(\overline{\xi}_{ij}, R_j) + \text{cov}(\Lambda_i^1, (1-h_j)\gamma_j R_j)}^{\text{Diversification}}$$
$$+ \underbrace{E[\overline{\xi}_{ij}] E[R_j]}_{\text{Liquidity}} + \underbrace{E[\Lambda_i^1] E[(1 - h_j)\gamma_j R_j]}_{\text{Collateral}} \tag{6}$$

where λ_i^0 is the nonnegative multiplier on the date 0 budget constraint (1). "Specialization" indicates that banks invest in assets with low marginal costs, $\frac{\partial \Phi_{ij}}{\partial I_{ij}}$, and high returns, r_{ij}. For example, banks may specialize in certain lending markets or may lend in underserviced markets. "Diversification" indicates that banks value assets that pay off in states where the value of

19. Formally, a competitive equilibrium of the global economy is a vector of allocations (c, D, I, L, L^A) and prices γ such that (i) the contract (c_i, D_i, I_i, L_i) is optimal for country i banks, given prices; (ii) purchases L_i^A are optimal for country i arbitrageurs, given prices; and the markets for liquidations clear. See Online Appendix A.1 for derivations of first-order conditions in this section.

bank wealth, reflected through $\Lambda_i^1(s)$, is high. Although banks are risk neutral in their preferences, a binding collateral constraint induces a higher marginal value of wealth as banks seek to avoid forced asset sales. "Liquidity" measures the value to banks of having more of an asset available to be liquidated when faced with binding collateral constraints and implies banks value liquid assets with a high Lagrange multiplier $\overline{\xi}_{ij}(s)$ (with a positive Lagrange multiplier indicating a corner solution, where the bank would prefer to liquidate more investment if it had more to liquidate). "Collateral" measures the value of an asset as collateral for rolling over debt at date 1, and is decreasing in both the haircut, $h_j(s)$, and the liquidation discount, $1 - \gamma_j(s)$.

III. Globally Optimal Policy

In this section, we study the optimal policy that would be adopted by a global planner looking to correct the pecuniary externalities that arise from the presence of prices in banks' constraints. This provides a natural benchmark of a globally Pareto-efficient allocation, which would be achieved with international cooperation. We contrast our main results in Section IV with this cooperative benchmark to study conditions under which independent country regulators can achieve the cooperative outcome even without international cooperation.[20]

The global planning problem is a constrained-efficient problem of choosing activities of all banks (c_i, D_i, I_i, L_i for all i) to maximize a weighted sum of bank welfare, $\int_i \omega_i \int_s c_i(s) f(s) ds di$, subject to the same constraints (equations (1), (2), (3)) as faced by banks, but internalizing the equilibrium pricing equation (4).[21] For expositional purposes, we place welfare weights of zero on arbitrageurs and show in Section VI.C that our main result on Pigouvian efficiency still holds under positive welfare weights. As with banks, the global planner in our model solves the constrained-efficient planning problem with commitment.

We characterize the solution of the global planning problem by its decentralization: the complete set of date 0 wedges $\tau = \{\tau_i^c, \tau_i^D, \tau_i^I, \tau_i^L\}$ and date 0 lump sum transfers $\mathscr{T}_i$ that

20. For expositional purposes, results in the main text are presented for interior solutions.

21. As usual, the constrained-efficient allocation may also involve lump-sum transfers between countries at date 0 to guarantee Pareto efficiency. See Dávila and Korinek (2018) and Korinek (2017).

implement the globally optimal allocation. The complete set of wedges placed on country i banks consists of a wedge $\tau_i^c(s)$ on consumption in state s; a wedge τ_i^D on date 0 debt; a wedge τ_{ij}^I on investment in country j; and a wedge $\tau_{ij}^L(s)$ on liquidations of country j assets in state s. A complete wedge approach is a conventional approach to studying constrained-efficient planning problems. However, in Online Appendix D.3, we show that the global optimum of Proposition 1 can also be implemented with explicit quantity restrictions, rather than wedges. We show in Section V that our results also apply to more conventional macroprudential instruments: our main results and the economic forces behind them extend to the case where ex ante controls over assets and liabilities are allowed but ex post controls over liquidations are not.

Formally, wedges are taxes on banks at date 0 (recall banks also solve with commitment), whose proceeds are remitted lump sum to the banks they are collected from. The total date 0 wedge burden borne by country i banks (excluding remissions) is $T_i = T_{ii} + \int_j T_{ij} dj$, where $T_{ii} = \tau_{ii}^c c_i + \tau_{ii}^D D_i + \tau_{ii}^I I_i + \tau_{ii}^L L_i$ is the burden from their domestic activities and $T_{ij} = \tau_{ij}^I I_j + \tau_{ij}^L L_{ij}$ is the burden from their foreign activities in country j. To ease exposition, we have adopted inner-product notation, where, for example, $\tau_{ii}^c c_i = \int_s \tau_{ii}^c(s) c_i(s) f(s) ds$. The equilibrium value T_i^* of revenue from wedges is remitted lump sum to country i banks at date 0, so that their date 0 budget constraint accounting for wedges and remissions is

$$\Phi_{ii}(I_{ii}) + \int_j \Phi_{ij}(I_{ij}) dj \leqslant A_i + D_i - T_i + T_i^*. \tag{7}$$

Throughout the article, we maintain the asterisk notation to denote revenue remissions.

Because the global planner has a complete set of (revenue-neutral) wedges for every aspect of banks' decision problems, the planner can incentivize banks to adopt the socially optimal allocation rules by setting the wedge equal to the gap between the marginal social value of a change in that activity, the social planner's FOC, and the marginal private value of a change in that activity. See the proof for a formal representation. This gives us a standard representation of decentralizations of constrained-efficient planning problems. The following proposition characterizes the decentralization of the globally constrained-efficient allocation in terms of these wedges.

PROPOSITION 1. *The globally efficient allocation can be decentralized using liquidation wedges*

$$\tau^L_{ji}(s) = -\underbrace{\Omega_{ii}(s)}_{\text{Domestic Spillovers}} - \underbrace{\int_{i'} \Omega_{i'i}(s)di'}_{\text{Foreign Spillovers}} \quad \underbrace{\forall j}_{\text{Equal Treatment}}, \tag{8}$$

where $\Omega_{ij}(s) \leqslant 0$ *is the spillover to bank i from changes in total liquidations in foreign country j, given by*

$$\Omega_{ij}(s) = \underbrace{\frac{\partial \gamma_i(s)}{\partial L^A_i(s)}}_{\text{Price Impact}} \Bigg[\underbrace{\frac{\Lambda^1_i(s)}{\lambda^0_i} L_{ij}(s)}_{\text{Distributive Externality}}$$

$$+ \underbrace{\frac{\Lambda^1_i(s)}{\lambda^0_i}\big(L_{ij}(s) + (1 - h_j(s))\big[R_j(s)I_{ij} - L_{ij}(s)\big]\big)}_{\text{Collateral Externality}} \Bigg], \tag{9}$$

All other wedges are 0.

The proof of Proposition 1, along with all other proofs, is in the Online Appendix. The globally efficient allocation corrects a fire sale spillover problem: higher liquidations reduce liquidation prices and collateral values, tightening banks' collateral constraints further and forcing further liquidations. Because both domestic and foreign banks hold domestic investment, the fire sale impacts both domestic banks (Domestic Spillovers) and all foreign banks (Foreign Spillovers). The effect on any individual bank is the product of the marginal change in the liquidation price (Price Impact) and the total effect of that price change on that bank. That total effect consists of two standard pecuniary externalities: distributive externalities and collateral externalities (Dávila and Korinek 2018). Distributive externalities reflect that an increase in the liquidation price increases the recovery value to banks from liquidating the asset, which is weighted by the marginal value of wealth, $\Lambda^1_i(s)$, in that state. Distributive externalities are larger when banks liquidate more of that asset, that is $L_{ij}(s)$ is high. Collateral externalities reflect the effect of the change in price on the binding collateral constraint. An increase in the liquidation price relaxes the collateral constraint because liquidations generate a greater recovery value to repay debt holders and because the collateral value for debt rollover increases. As a result, foreign spillovers are particularly large when foreign banks are forced to liquidate domestic assets or face binding collateral constraints at the same time the domestic liquidation price is particularly sensitive to additional liquidations.

Because both domestic and foreign banks can contribute to the domestic fire sale via liquidations, globally efficient policy applies wedges to both domestic and foreign banks. Moreover, globally efficient policy applies equal treatment: the wedge placed on liquidations of the country i asset does not depend on the domicile of the bank liquidating it. This is because domestic and foreign banks generate the same total spillover by liquidating a domestic project. Although foreign banks can contribute to domestic instability by retrenching, they are not treated differently from domestic banks under the globally efficient policy.

IV. Noncooperative Policies

The globally efficient policy of Section III is predicated on a global planner setting policy. However, in practice countries have regulatory jurisdiction over banks within their borders. In this section, we present the main result: whereas independent governments using quantity regulation are unable to achieve efficient policy, independent governments using Pigouvian taxation are able to achieve the efficient outcome provided that monopoly rents are zero.

IV.A. Country Planners

Each country has a designated government, or social planner, who represents and acts in the interests of domestic agents. The social welfare function of country planner i is equal to domestic bank welfare, $\int_s c_i(s) f(s) ds$.[22] The social planner of each country has a complete set of wedges on domestic banks and domestic allocations of foreign banks. The wedges of the country i planner on country i banks are $\tau_{i,i} = (\tau^c_{i,i}, \tau^D_{i,i}, \tau^I_{i,i}, \tau^L_{i,i})$, and are fully contingent as in Section III. The fully contingent wedges of the country i planner on country j banks are $\tau_{i,j} = (\tau^I_{i,ji}, \tau^L_{i,ji})$, reflecting that the country i planner can only directly influence the domestic

22. We have assumed banks are wholly domestically owned. Online Appendix D.1 allows for partial foreign ownership of domestic banks and shows that Pigouvian taxation remains efficient.

activities of foreign banks.[23] To clarify notation, the index before the comma indicates the identity of the country planner placing the wedge, while the indexing after the comma (combined with the superscript) indicates the bank and activity the wedge is being placed on. Furthermore, observe that there is common agency: both the planner of country i and the planner of country j have wedges over the investment ($\tau^I_{i,ij}$ and $\tau^I_{j,ij}$, respectively) and liquidations ($\tau^L_{i,ij}$ and $\tau^L_{j,ij}$) of country i banks in country j.

As in Section III, these wedges are taxes from the perspective of banks, meaning that revenue is collected from their use. The total date 0 wedge burden borne by country i banks (excluding remissions) is $T_{i,i} + \int_j T_{j,\,ij} dj$, where $T_{i,i} = \tau^c_{i,i} c_i + \tau^D_{i,i} D_i + \tau^I_{i,i} I_i + \tau^L_{i,i} L_i$ is the wedge burden owed by domestic banks to the domestic planner and $T_{j,ij} = \tau^I_{j,ij} I_{ij} + \tau^L_{j,ij} L_{ij}$ is the wedge burden owed by domestic banks to foreign planner j. Note that the index prior to the comma again refers to the planner to whom wedge revenues are owed.

1. *Quantity Regulation versus Pigouvian Taxation.* In Section III, proceeds from these wedges were remitted lump sum to the banks they were collected from. In this section, we differentiate between two instruments—quantity regulation and Pigouvian taxation—based on the revenue remission rule for revenues collected from wedges on foreign banks. The equilibrium tax revenue $T^*_{i,i}$ collected from domestic banks is always remitted lump sum to domestic banks.

We refer to revenue-neutral wedges on foreign banks as quantity restrictions, appealing to duality results between revenue-neutral taxes and quantity restrictions in problems with a single regulator.[24] Moreover, in Online Appendix D.3, we verify that the optimum characterized in Proposition 2 is also attained when country planners utilize explicit quantity restrictions, rather than revenue-neutral wedges. Under quantity regulation (i.e., revenue-neutral wedges), tax revenue collected from foreign banks is remitted globally to foreign banks according to a remission rule $T^{*,\text{Quantity}}_{i,-i} = T^G_i$, which is taken as given by

23. Because wedges are the means of controlling allocations, we rule out explicit side payments.

24. For example, Erten, Korinek, and Ocampo (2021, 63) argue that “the principle of dualism...implies that every quantity-based control corresponds to an equivalent price-based control.”

country i.[25] In particular, planner i does not internalize the effect of how domestic taxes on foreign banks change the remitted tax revenue $T^{*,\text{Quantity}}_{i,-i}$. Wedges under the quantity regulation remission rule are used to control allocations but do not generate revenues for the domestic planner.

By contrast, we refer to revenue-generating wedges as Pigouvian taxation. Under Pigouvian taxation, the equilibrium tax revenue collected from foreign banks is remitted to domestic banks. This generates total remissions $T^{*,\text{Pigou}}_{i,-i} = \int_j T_{i,ji} dj$ to domestic banks. In contrast to quantity regulation, the country i planner now accounts for how changes in policy affect revenue collected from foreign banks because it translates directly into changes in revenues remitted to domestic banks.

In both cases, taxes appear in the banks' date 0 budget constraint, now given by

$$\Phi_{ii}(I_{ii}) + \int_j \Phi_{ij}(I_{ij}) dj \leqslant A_i + D_i - \underbrace{T_{i,i} - \int_j T_{j,ij} dj}_{\text{Total Tax Burden}} + \underbrace{T^*_{i,i} + T^*_{i,-i}}_{\text{Total Remissions}}, \tag{10}$$

where $T^*_{i,-i} \in \{T^{*,\text{Quantity}}_{i,-i}, T^{*,\text{Pigou}}_{i,-i}\}$, depending on the policy regime. Banks optimally choose contracts as in Section II, now taking into account the additional tax burden. Notice that equation (10) is identical to the budget constraint in Section III, up to the different remission rules. This means that collectively, country planners have the same total set of instruments the global planner does. In contrast to the global planner, however, different country planners set different instruments independently of one another, and there are some instruments that multiple country planners possess (common agency).

2. *Equilibrium Concept.* A noncooperative equilibrium of the model is a Nash equilibrium between country planners, in which every country planner optimally chooses wedges $\tau_i = (\tau_{i,i}, \{\tau_{i,j}\})$ to maximize domestic social welfare, taking as given the wedges τ_{-i} set by all other country planners.

25. In particular, there is the globally remitted revenue $T^G = \int_i \int_j T^*_{i,ji} dj di$ arising from the wedges, which corresponds to remitting revenue to foreigners. We assume this is remitted according to some allocation rule $\int_i T^G_i di = T^G$.

3. *Implementability.* Banks are subject to wedges by planners in all countries they operate in. Moreover, although country planner i has a complete set of controls over domestic banks, she has only a partial set of controls over foreign banks. Nevertheless, we provide an implementability result that allows us to solve the problem using a standard approach of directly choosing allocations and then backing out the wedges that implement that allocation.

LEMMA 1 (Implementability). *Under both quantity regulation and Pigouvian taxation, the optimization problem of country planner i can be written as maximizing social welfare by directly choosing allocations (c_i, D_i, I_i, L_i, $\{I_{ji}, L_{ji}\}_j$), subject to equations (10), (2), (3), and (4), taking as given τ_{-i} and γ_{-i}. The implementing wedges for the domestic allocations of foreign banks are*

(11)
$$\tau^I_{i,ji} = -\tau^I_{j,ji} - \frac{\partial \Phi_{ji}}{\partial I_{ji}} + E\left[\frac{\lambda^1_j}{\lambda^0_j}(1+r_{ji})R_i\right] + \frac{1}{\lambda^0_j}E\left[\Lambda^1_j(1-h_i)\gamma_i R_i\right]$$

(12)
$$\tau^L_{i,ji}(s) = -\tau^L_{j,ji}(s) + \frac{\lambda^1_j(s)}{\lambda^0_j}\big(\gamma_i(s) - (1+r_{ji})\big) + \frac{1}{\lambda^0_j}\Lambda^1_j(s)h_i(s)\gamma_i(s),$$

where country planner i takes the Lagrange multipliers λ^0_j, $\lambda^1_j(s)$, and $\Lambda^1_j(s)$ as given (for $j \neq i$).

IV.B. Noncooperative Quantity Regulation

We characterize the noncooperative equilibrium under quantity regulation, where revenue from wedges on foreign banks is remitted to foreign banks.

PROPOSITION 2. *The noncooperative equilibrium under quantity regulation has the following features.*

i. *The domestic liquidation wedges on domestic banks are*

(13)
$$\tau^L_{i,ii}(s) = -\underbrace{\Omega_{ii}(s)}_{\text{Domestic Spillovers}},$$

where Ω_{ii} is defined as in Proposition 1.

ii. *The domestic liquidation wedges on foreign banks generate an allocation rule*

$$L_{ji}(s) \underbrace{\Omega_{ii}(s)}_{\text{Domestic Spillovers}} = 0.$$

In other words, if $|\Omega_{ii}(s)| > 0$ *then* $\tau^{L}_{i,ji}(s)$ *is set high enough that foreign banks do not liquidate domestic assets in state* s.

iii. *All other wedges on domestic and foreign banks are* 0.

Proposition 2 reflects how country planners use quantity regulation to manage fire sale spillovers. First, country planners place wedges on domestic liquidations by domestic banks that account for the fire sale spillover cost to domestic banks. Because planners do not care about the welfare of foreign banks, the domestic wedges do not account for spillovers to foreign banks.

Second, country planners place wedges on liquidations by foreign banks. Because planners again do not care about foreign bank welfare, they find it optimal to prohibit foreign banks from contributing to the domestic fire sale whenever there is an adverse domestic spillover, even while allowing domestic banks to liquidate domestic assets. This effective ban on domestic liquidations by foreign banks (e.g., a ban on outflows) is too strong in practice and arises because there is no domestic benefit to foreign investment in the baseline model. Less strong versions of this result arise under the same logic if foreign banks generate some benefits to the domestic economy: because country planners are not concerned with the welfare of foreign banks, they continue to underregulate domestic banks (neglecting spillovers to foreign banks) and impose unequal treatment (neglecting benefits to foreign banks).[26]

Finally, the domestic planner does not tax foreign liquidations by domestic banks. This happens because the investment presence of domestic banks in any single foreign country is marginal, so that country planners do not internalize their fire sale impact in foreign countries.

26. See Examples 1 and 2 of Section VI as well as Online Appendix D.5 for details. Unlike in Proposition 2, unequal treatment can take the form of foreign banks also being underregulated relative to the global optimum, but still being regulated differently from domestic banks.

1. *Optimal Cooperation.* Noncooperative quantity regulation differs from globally efficient policy in two important ways. First, noncooperative quantity regulation does not account for foreign spillovers, so the globally efficient wedge $\tau_{ii}^{L}(s)$ is generally higher than the noncooperative wedge $\tau_{i,ii}^{L}(s)$. Noncooperative regulation features too little regulation of domestic banks due to the foreign spillovers from domestic fire sales. This is a multilateral problem, as the domestic fire sale potentially affects all foreign countries investing domestically. Second, noncooperative quantity regulation results in unequal treatment of foreign banks for domestic activities—foreign banks are regulated more stringently than domestic banks. This regulatory gap $\tau_{i,ji}^{L}(s) - \tau_{i,ii}^{L}(s)$ reflects a bilateral problem: the marginal benefit to foreign banks of liquidating the domestic asset outweighs the marginal cost to the domestic economy. Nevertheless, foreign liquidations are banned because that positive surplus accrues to foreign banks and not to the domestic economy.

IV.C. Noncooperative Pigouvian Taxation

We characterize the noncooperative equilibrium under Pigouvian taxation, where wedge revenues from foreign banks are remitted domestically. Recall that the change in the remission rule is the only difference relative to quantity regulation. The next two propositions provide our main result: that country planners using noncooperative Pigouvian taxation achieve the globally efficient outcome, absent monopoly rents.

PROPOSITION 3. *The noncooperative equilibrium under Pigouvian taxation has the following features.*

i. *The domestic liquidation wedges on domestic and foreign banks are*

$$\tau_{i,ii}^{L}(s)=\tau_{i,ji}^{L}(s)=-\underbrace{\Omega_{ii}(s)}_{\text{Domestic Spillovers}}-\underbrace{\int_{i'}\Omega_{i'i}(s)di'}_{\text{Foreign Spillovers}}\underbrace{\forall j}_{\text{Equal Treatment}}, \tag{14}$$

where $\Omega_{ij}(s)$ are as defined in Proposition 1.

ii. *The wedges on domestic investment by foreign banks are*

$$\tau^I_{i,ji} = \underbrace{\frac{\partial^2 \Phi_{ji}}{\partial I^2_{ji}} I_{ji}}_{\text{Monopolist Motive}} \geqslant 0.$$

iii. *All other wedges are* 0.

In contrast to quantity regulation, noncooperative planners using Pigouvian taxation implement the efficient wedges on asset liquidations. This difference arises from the motive to collect revenue from foreign banks. To build intuition, we begin with an informal and economic discussion of how the revenue motive leads to the efficient outcome. We will show the formal steps for why it leads to fully efficient policy. For expositional purposes, in the arguments that follow we set $h_i(s) = 1$, that is banks are unable to use assets as collateral. The general case is contained in the proof.

Economically, there are three consequences for tax revenue collection of allowing foreign bank j to increase liquidations $L_{ji}(s)$ of the domestic asset. The first two, the direct effect (DE) and the monopoly effect (ME), capture the effect of the change $dL_{ji}(s)$ on revenue collected from bank j. The third, the price effect (PE), is the effect of the change $dL_{ji}(s)$ on revenue collected from all other foreign banks i' due to changes in the equilibrium liquidation price $\gamma_i(s)$.

Consider first the DE. In the noncooperative equilibrium, country planner i collects total revenue $\tau^L_{i,ji}(s)L_{ji}(s)$ from bank j for asset liquidations in state s. This means that by allowing an increase $dL_{ji}(s)$ in asset liquidations, there is a direct increase $\tau^L_{i,ji}(s) \cdot dL_{ji}(s)$ in revenue collected from bank j. In equilibrium, the tax rate $\tau^L_{i,ji}(s)$ charged to bank j for liquidations (i.e., the private marginal cost) must be equal to the private marginal benefit to bank j of liquidating the domestic asset. In other words, DE captures the forgone private marginal surplus to bank j as a result of regulation that rules out an increase $dL_{ji}(s)$.[27]

27. The direct effect is thus analogous to the distinction identified in the trade literature in the introduction. Viewed in that context, we might think of $\tau^L_{i,ji}(s)$ as a tariff on the foreign bank, with the marginal surplus of an additional marginal unit of liquidations being collected by the country i planner as tariff revenue, rather than being retained by the foreign bank. This shifting of the marginal surplus from the foreign bank to the domestic government is behind the direct effect.

The second effect, the ME, is the second aspect of the change in revenue collected from bank j: in response to an increase $dL_{ji}(s)$, there is an effect $\frac{\partial \tau^L_{i,ji}(s)}{\partial L_{ji}(s)}$ on the tax rate that can be charged.[28] From Lemma 1, we see that $\frac{\partial \tau^L_{i,ji}(s)}{\partial L_{ji}(s)} = 0$, meaning that the partial-equilibrium elasticity of liquidations with respect to the liquidation tax rate is infinite, that is, a small increase in the tax rate leads bank j to stop liquidating the country i asset. In other words, this is a conventional case of perfect competition between countries in their respective markets for liquidations, as an attempt by one country to further increase their tax rate leads foreign banks to instead liquidate in other countries. The ME is therefore zero.

The third effect, the PE, reflects that a change in the equilibrium price $\gamma_i(s)$ as a result of a change in liquidations affects the tax rate that can be charged to a bank. This has a corresponding effect $\frac{\partial \gamma_i(s)}{\partial L^A_i(s)} \cdot \frac{\partial \tau^L_{i,i'i}(s)}{\partial \gamma_i(s)} \cdot L_{i'i}(s)$ on revenue collected from bank i' for liquidations. In contrast to ME, this term is not zero: an increase in the price $\gamma_i(s)$ increases the marginal value to bank j of liquidating that asset, so increases the tax rate that can be charged. In other words, mitigating the domestic fire sale serves to increase the revenue that can be collected from foreign banks. Drawing from the tax formulas of Lemma 1, we can see that this effect is given by

$$\frac{\partial \gamma_i(s)}{\partial L^A_i(s)} \cdot \frac{\partial \tau^L_{i,i'i}(s)}{\partial \gamma_i(s)} \cdot L_{i'i}(s) = \frac{\partial \gamma_i(s)}{\partial L^A_i(s)} \Bigg[\underbrace{\frac{\lambda^1_{i'}(s)}{\lambda^0_{i'}} L_{i'i}(s)}_{\text{Distributive Externality}} + \underbrace{\frac{1}{\lambda^0_{i'}} \Lambda^1_{i'}(s) L_{i'i}(s)}_{\text{Collateral Externality}} \Bigg] = \Omega_{i'i}(s).$$

The first term captures the effect of the price change on revenue collected from asset liquidations and corresponds to the distributive externality of Proposition 1. The second term captures the ability of liquidations to relax the collateral constraint and reflects the entire collateral externality of Proposition 1 when $h_i(s) = 1$ and debt cannot be rolled over. Thus, the combination of these revenue effects generates the spillover $\Omega_{i'i}(s)$.

28. There is also an analogous effect on $\tau^I_{i,ji}$, which we omit here for exposition but is detailed below.

We now put these terms together into the formal argument. Given revenue collected $\Pi_i = \int_{i'}[\tau^I_{i,i'i} I_{i'i} + \tau^L_{i,i'i} L_{i'i}]di'$, the first-order condition of planner i for bank j liquidations $L_{ji}(s)$ is given by

$$0 = \underbrace{\Omega_{ii}(s)}_{\text{Domestic Spillovers}}$$

$$\underbrace{+\overbrace{\tau^L_{i,ji}(s)}^{\text{DE}} + \overbrace{\frac{\partial \tau^I_{i,ji}}{\partial L_{ji}(s)} I_{ji} + \frac{\partial \tau^L_{i,ji}}{\partial L_{ji}(s)} L_{ji}}^{\text{ME}} + \overbrace{\frac{\partial \gamma_i(s)}{\partial L^A_i(s)} \int_{i'} \left[\frac{\partial \tau^I_{i,i'i}}{\partial \gamma_i(s)} I_{i'i} + \frac{\partial \tau^L_{i,i'i}}{\partial \gamma_i(s)} L_{i'i}\right] di'}^{\text{PE}}}_{\text{Impact on Revenue}}$$

$$= \underbrace{\Omega_{ii}(s)}_{\text{Domestic Spillovers}} \underbrace{+\overbrace{\tau^L_{i,ji}(s)}^{\text{DE}} + \overbrace{0}^{\text{ME}} + \overbrace{\int_{i'} \Omega_{i'i}(s) di'}^{\text{PE}}}_{\text{Impact on Revenue}},$$

resulting in efficiency. Notice that in this case with $h_i(s) = 1$, we had $\frac{\partial \tau^I_{i,ji}}{\partial \gamma_i(s)} = 0$. This is because investment has no value as collateral when $h_i(s) = 1$, and debt cannot be rolled over.

The ME in the market for liquidations was zero, reflecting perfect competition between country planners in this market. When considering the analogous effect in the market for initial investment, we have the term $\frac{\partial \tau^I_{i,ji}}{\partial I_{ji}} = -\frac{\partial^2 \Phi_{ji}}{\partial I^2_{ji}}$.[29] Thus, to ensure absence of monopoly rents in the market for investment, we need $\frac{\partial^2 \Phi_{ji}}{\partial I^2_{ji}} = 0$, that is, there is also perfect competition in this market. Notably, noncooperative regulators set wedges on liquidations according to the correct equation even with monopoly rents for initial investment. As such, even if there is an investment scale distortion, regulators using Pigouvian taxes achieve the correct Pigouvian tax on liquidations, after accounting for the distorted investment scale.

29. Note that we have expressed this motive as a derivative of price (tax rate) in the quantity. This is equivalent to expressing it in a more familiar way of a derivative of quantity (demand) in price. In our model, it is simpler to solve for quantities and then back out the implementing prices (taxes).

1. *Efficiency of Noncooperative Pigouvian Taxation.* Under Pigouvian taxation, the noncooperative equilibrium differs from efficient policy only because of the monopolist motive that leads to taxes on foreign investment. If countries are substitutable with other countries from an investment perspective, monopoly power will be small. In the limit where monopoly power is zero, noncooperative taxation implements the globally efficient outcome, eliminating the need for cooperation.

PROPOSITION 4. *Suppose that for all i and $j \neq i$, $\frac{\partial^2 \Phi_{ij}}{\partial I_{ij}^2} = 0$. Then the noncooperative equilibrium under taxation is globally efficient. There is no scope for cooperation.*

Proposition 4 suggests that an alternative to cooperative regulatory agreements exists in the model. If countries switch to Pigouvian taxation to manage fire sale spillovers, country planners can achieve the cooperative outcome in a noncooperative manner. They do so even though each country maximizes domestic welfare only, even though domestic liquidation prices appear in foreign bank constraints, and even though domestic planners have market power over domestic liquidation prices.

The sufficient condition of Proposition 4 requires a notion of substitutability between countries. The condition $\frac{\partial^2 \Phi_{ij}}{\partial I_{ij}^2} = 0$ implies that the (partial-equilibrium) elasticity of investment with respect to the tax rate is infinite. The infinite elasticity is a limiting case in which countries have no monopoly power over foreign banks and implement an efficient outcome.

Proposition 4 provides an exact efficiency result in a limiting case of an infinite elasticity. Even if countries have some monopoly power, Pigouvian taxation in Proposition 3 provides three potential advantages. First, it restricts the need for cooperation to cooperation over regulation of foreign activities of banks. Second, it transforms the source of inefficiency from a multilateral spillover problem into a bilateral monopolist problem, which may be able to be solved for example by tax treaties. Third, it changes the information required to determine the need for and terms of a cooperative agreement to a set of partial-equilibrium elasticities of investment with respect to the tax rate (the cost of investment). Cooperation is required when the elasticity of investment in the tax rate (cost of investment) is low and not required when it is high. By contrast, cooperation under quantity regulation requires evaluating a set of multilateral general-equilibrium financial stability spillovers, and there may be substantial disagreements between countries as to their magnitudes and cross-country correlations.

IV.D. Discussion

In practice, macroprudential regulatory requirements—such as minimum equity capital and liquidity requirements—commonly take the form of quantity restrictions. However, use of Pigouvian taxes, such as a tax on debt, has been discussed as an alternative (Kocherlakota 2010; Cochrane 2014; De Nicoló, Favara, and Ratnovski 2014; Tucker 2016). On the other hand, emerging markets in practice use both quantity- and price-based capital control measures to manage capital flows (IMF 2012). Our model implies that, provided that monopoly power is low, price-based regulation and capital control measures are efficient, whereas quantity-based measures are not. We thus provide an efficiency-based argument in favor of a Pigouvian tax approach to macroprudential policies, which we further develop in Section V.

In addition to this normative implication for the design of bank regulation, our model also helps us understand the broad architecture of existing cooperative agreements. The model suggests that noncooperative quantity regulation of domestic banks is overly lax while there is also unequal treatment of foreign banks. Both the Basel III accords and the European Banking Union aim to enhance bank regulatory standards to address cross-border stability risks, for example, by strengthening bank capital and liquidity requirements. Moreover, equal treatment is recognized as an important aspect of cooperation.[30]

Importantly, cooperation is often perceived to be difficult when countries are sufficiently asymmetric.[31] Asymmetric agreements may require explicit international transfers, which may be politically difficult to implement. Pigouvian taxation implements the required transfers in a decentralized way through the revenues collected and may help facilitate efficient outcomes when

30. For example, Basel III "rais[es] the resilience of the banking sector by strengthening the regulatory capital framework" (BIS 2010), and the ECB lists one of the goals of the SSM as "ensuring a level playing field and equal treatment of all supervised institutions" (ECB 2018).

31. See Bolton and Oehmke (2019) and Dell'Ariccia and Marquez (2006).

countries are relatively asymmetric (e.g., developed economies and emerging markets).

One interesting property of our model is that noncooperative regulators using quantity restrictions ban capital outflows (see also Caballero and Simsek 2020) but allow outflows (subject to a tax) when using Pigouvian taxation. This suggests that after moving to a Pigouvian regime, we might expect an increase in observed capital retrenchment. However, this needs a caveat. If there are domestic benefits from foreign banking, optimal quantity restrictions may result in unequal treatment but not a complete ban on outflows (see Online Appendix D.5). Noncooperative regulators may in fact underregulate foreign banks relative to the global optimum, accounting for the net positive benefit to the domestic economy but not for foreign spillovers. We might thus conjecture that following a switch to a Pigouvian regime, countries with small (large) benefits from foreign banking would see more (less) capital retrenchment.

1. *Practical Concerns with Taxation.* Financial regulation in practice commonly takes the form of quantity restrictions, rather than Pigouvian taxation. This leads to the natural concern that our model fails to account for the reasons the current regulatory framework favors quantity restrictions over taxes. One possibility is that Pigouvian taxation may simply be perceived as roughly equivalent to quantity regulation. Even in academic debates, duality is a common assumption, particularly since quantity regulation can include tax-like features such as risk weights and capital surcharges.[32] Moreover, even though governments and regulators likely recognize the ability of Pigouvian taxes to raise revenues, it may not be appreciated that the revenue collection incentive can actually promote efficient regulation of cross-border banks, which is our main contribution.

Nevertheless, in practice quantity regulations and revenue-neutral linear Pigouvian taxes may not be dual when regulators face uncertainty (Weitzman 1974). For example, this violation of duality might arise in our model if regulators face uncertainty about bank productivity.[33] What follows is an illustrative verbal

32. See Greenwood et al. (2017) for a discussion of tax-like features of quantity regulation.

33. See Perotti and Suarez (2011) for formal analysis along these lines, and Tucker (2016) for further discussion.

example. Suppose that bank productivity is known, and suppose that the global optimum allows greater fire sales when bank productivity is higher to allow banks to capitalize on higher productivity. This means the optimal tax on liquidations should increase in bank productivity since externalities are greater. Now suppose that bank productivity is not known to the regulator. If the global planner imposes a quantity ceiling on liquidations, low-productivity banks fall below the ceiling and face an unconstrained choice, whereas high-productivity banks are pooled together at the binding ceiling. As a result, low-productivity banks that fall below the ceiling are underregulated in equilibrium, while particularly high-productivity banks that face a binding cap are overregulated. By contrast, a linear tax applies the same tax rate regardless of productivity, meaning that low-productivity banks are overregulated while high-productivity banks are underregulated. Uncertainty gives rise to a violation of duality in this setting, which is different from the revenue motives we study, and in particular this violation of duality applies also to the global planner. Notably, the key issue here is that the optimal tax with certainty is nonlinear in productivity. The optimal regime in this setting may thus feature nonlinear taxation, rather than linear taxes or quantity restrictions (Roberts and Spence 1976; Spence 1977).

There are several additional economic and political concerns that may arise from use of taxation. One prominent practical concern is that a race to the bottom may undermine a regulatory use of taxes in practice. A race to the bottom is a common concern in bank regulation (Dell'Ariccia and Marquez 2006) and in debates on corporate taxation.[34] Interestingly, competition among country planners in our model results in efficiency, rather than a race to the bottom. A second practical concern may be that setting the correct taxes could be difficult in practice. In our model, the same information—the social cost $\tau_i^L(s)$—is required to set either the optimal tax or the optimal quantity restriction. This observation is further developed in Section V, where optimal macroprudential quantity restrictions (e.g., leverage and liquidity requirements) are in fact characterized in terms of the optimal Pigouvian taxes. A third practical concern is that there may be important

34. For example, U.S. Treasury Secretary Janet Yellen cited concerns about a race to the bottom in advocating for a global minimum corporate tax. "Yellen: 'Global Race to the Bottom' in Corporate Tax," BBC News (2021).

political impediments to our proposal. Pigouvian taxation may be politically more difficult to implement than quantity restrictions because of perceived unpopularity of taxes, particularly if the burden of the tax is perceived to be borne by consumers.[35] Moreover, applying taxes may lead to political lobbying for tax revenues (e.g., Bhagwati and Srinivasan 1980; Cassing and Hillman 1985), which might also undermine efficiency.

This subsection has taken a first step toward establishing and discussing several potential concerns with our proposal. These concerns, among others, may represent important practical limitations that will have to be evaluated against the merits of the Pigouvian tax approach to bank regulation identified herein.

2. *The Role of Commitment.* In our model, banks commit to liquidation rules L_i and planners commit to taxes on liquidations at the same time as investment I_i is being undertaken. In Online Appendix D.4, we show that a time consistency problem can arise absent commitment because planners at date 1 neglect the impact of date 1 policies on the date 0 value of investment, which is partly driven by its value as collateral.[36] Because part of the revenue effect of liquidation taxes derives from the collateral value of investment, this can undermine Pigouvian efficiency.[37] The time consistency problem disappears when we consider macroprudential capital and liquidity regulation in Section V, where policies are set at date 0. Section V also considers resolution and bailout policies, and we provide further discussion of commitment in those settings. In fact, in Section V.D, we provide an alternative interpretation of the baseline model in which banks effectively commit to ex post liquidation policies through ex ante (date 0) organizational choices—for example, by using explicit

35. While outside the banking context, see Mankiw (2009) and Masur and Posner (2015). Baker et al. (2017) argues that revenue neutrality is important to ensure political support for a carbon tax.

36. Notably, this time consistency problem arises because the collateral value is based on the date 1 price $\gamma_j(s)$ and would not arise if it were based on the date 2 price $1 + r_{ij}$.

37. The time consistency problem that arises is similar to the problem studied in Farhi and Tirole (2018). In their paper, regulation is set after debt has been sold to foreign investors, leading the regulator to fail to internalize the effect of regulation on the price of debt. Here, if planners set taxes on liquidations after investment has been determined, then planners neglect the effect of liquidation taxes on revenue collected from taxes on investment.

debt guarantees, employing single- versus multi-point-of-entry resolution, or expansion using branches versus subsidiaries. In this interpretation, efficiency is achieved through an entry fee charged to banks based on date 0 organizational form, rather than through ex post liquidation taxes.

V. Applications to Macroprudential Regulation

In this section, we apply our theory to more conventional regulatory tools—bank equity capital and liquidity requirements—and bank resolution policies—cross-border support and bailouts. These policies are important centerpieces of postcrisis regulation and cooperative arrangements.[38] Our applications shed light on the practical implications of our results for the design of regulation. Under noncooperative quantity regulation, country planners engage in various forms of ring-fencing of foreign banks: excessive leverage restrictions, excessive liquidity requirements, hoarding of loss-absorbing capital, and underprovision of fiscal backstops. Moreover, country planners underregulate domestic banks along each of these dimensions. This motivates a cooperative regime that provides for equal treatment of foreign banks and increases regulation of domestic banks. By contrast, noncooperative planners using Pigouvian taxation implement the efficient outcome, absent monopoly rents. Efficiency is achieved through a combination of (i) a tax on subsidiary debt issuance and a subsidy on illiquid assets, in place of a leverage requirement; (ii) a subsidy on liquid assets, in place of a liquidity requirement; (iii) a tax on loss-absorbing capital by which the subsidiary recapitalizes the parent, replacing an orderly resolution requirement; and (iv) a fee charged to banks for the bailouts they expect to receive.

V.A. A Model with Macroprudential Regulation

We formulate a variant of the baseline model under which ex ante restrictions on banks, rather than ex post liquidation taxes, serve as the method of controlling bank behavior. Doing so requires establishing how decisions at the country-level affect liquidations in that country. To this end, we interpret bank i as a bank holding company, located in country i, which owns and operates

38. Common standards for equity capital and liquidity requirements are core elements of both Basel III and the European Banking Union, and common resolution and fiscal backstops are pillars of the European Banking Union.

subsidiaries in different countries, with ij denoting its subsidiary in country j. In this section we assume subsidiaries do not support each other in distress, an assumption we relax in Section V.D.

At date 0, bank i allocates its total initial funds A_i across its subsidiaries, with E_{ij} denoting the "equity" allocation to the subsidiary in country j and E_i denoting the portfolio of equity allocations. In exchange, bank i receives the entire equity claim of the subsidiary. Equity allocation is subject to the budget constraint $E_{ii} + \int_j E_{ij} dj = A_i$. In addition, subsidiary ij can issue debt D_{ij} to finance investment, so the budget constraint of subsidiary ij is $\Phi_{ij}(I_{ij}) \leqslant E_{ij} + D_{ij}$.[39] The shock and return structure are the same as in the baseline model but now subsidiary ij is responsible for its debt rollover and faces a collateral constraint $D_{ij} \leqslant \gamma_j(s)L_{ij}(s) + (1 - h_j(s))\gamma_j(s)[R_j(s)I_{ij} - L_{ij}(s)]$. Rearranging the collateral constraint, liquidations of subsidiary ij are given by

$$L_{ij}(s) = \frac{1}{h_j(s)\gamma_j(s)} \max\left\{D_{ij} - d_j^*(s)I_{ij}, 0\right\}, \tag{15}$$

where $d_j^*(s) \equiv (1 - h_j(s))\gamma_j(s)R_j(s)$ reflects the collateralizability of investment. Liquidations are increasing in leverage $d_{ij} \equiv \frac{D_{ij}}{I_{ij}}$, increasing in absolute debt level D_{ij}, and decreasing in scale I_{ij}. Define the region of distress of subsidiary ij as the set of states s in which it is forced to liquidate assets, that is,

$$S_{ij}^D = \{s \in S | D_{ij} > d_j^*(s)I_{ij}\}. \tag{16}$$

We further define $d_j^* = \inf_{s \in S} d_j^*(s)$ as the highest leverage subsidiary ij can undertake without ever being forced to liquidate assets, that is, so that $S_{ij}^D = \emptyset$.

The final equity payoff of subsidiary ij at date 2 is given by $c_{ij}(s) = \gamma_j(s)L_{ij}(s) + (1 + r_{ij})[R_j(s)I_{ij} - L_{ij}(s)] - D_{ij}$, so that the total equity payoff of bank i is $c_i(s) = c_{ii}(s) + \int_j c_{ij}(s)dj$. The problem of bank i is therefore to choose (E_i, D_i, I_i) to maximize expected equity payoff, $E[c_i(s)]$, subject to the budget constraint of the holding company, the budget constraints of the subsidiaries, and the liquidation rule of equation (15).

39. Notice that combining these equations by substituting out equity E_{ij} gives the consolidated budget constraint (1) in the baseline model.

1. *Commitment.* In the baseline model, we solved the problem with commitment because liquidations occurred at date 1 and were regulated. Up through and including the liquidity model of Section V.C, regulatory decisions considered in this section affect bank choices at date 0, meaning the assumption of commitment is now immaterial. We will provide further discussion of commitment in Section V.D, when we introduce cross-border support.

2. *Arbitrageurs and Aggregate Liquidations.* Arbitrageurs are defined analogously to the baseline model, but aggregate liquidations in state s by all subsidiaries in country i are now endogenous to the price through the collateral constraint. In particular, defining $D_i^A(s) = D_{ii}\mathbf{1}_{s\in S_{ii}^D} + \int_{i'|s\in S_{i'i}^D} D_{i'i}di'$ to be the aggregate debt of distressed subsidiaries in country i in state s (and similarly for $I_i^A(s)$), then aggregate liquidations in country i in state s are given by $L_i^A(s) = \frac{1}{h_i(s)\gamma_i(s)}[D_i^A(s) - d_j^*(s)I_i^A(s)]$.

V.B. Optimal Regulation

We now turn to characterizing optimal policy. Planners still have a complete set of instruments for the date 0 choices of banks, which now correspond to wedges on subsidiary debt, τ_{ij}^D, and on subsidiary investment, τ_{ij}^I. As before, we denote revenue-neutral wedges to be quantity regulation, and revenue-generating wedges to be Pigouvian taxation. We also provide mappings of optimal policy under revenue-neutral wedges into explicit quantity restrictions.

We begin by characterizing globally optimal regulation.

PROPOSITION 5. *The globally efficient allocation can be decentralized using wedges*

$$\tau_{ji}^D = \underbrace{\overbrace{\Pr\left(s \in S_{ji}^D\right)}^{\text{Probability of Distress}} \times \overbrace{\mathbb{E}\left[\tau_i^L(s)\frac{1}{h_i(s)\gamma_i(s)}\middle| s \in S_{ji}^D\right]}^{\text{Social Cost of Debt in Distress}}}_{\geqslant 0},$$

$$\tau_{ji}^I = \underbrace{\Pr\left(s \in S_{ji}^D\right) \cdot \mathbb{E}\left[\tau_i^L(s)\frac{-d_i^*(s)}{h_i(s)\gamma_i(s)}\middle| s \in S_{ji}^D\right]}_{\leqslant 0},$$

where the total social cost $\tau_i^L(s) \geqslant 0$ *of liquidations in country* i *in state* s *is*

$$\tau_i^L(s) = \underbrace{\left|\frac{d\gamma_i(s)}{dL_i^A(s)}\right|}_{\text{Total Price Impact}} \cdot \underbrace{\frac{1}{h_i(s)\gamma_i(s)}\left[\frac{1}{\gamma_i(s)}D_i^A(s) - d_i^*(s)I_i^A(s)\right]}_{\text{Total Fire Sale Spillover}},$$

where the total price effect $\frac{d\gamma_i(s)}{dL_i^A(s)}$ *is defined in the proof.*

The intuition of Proposition 5 is similar to that of the baseline model. All else equal, an increase in the debt level D_{ji} of subsidiary ji increases liquidations in state s when it is in distress, which leads to a fire sale spillover to domestic and foreign banks. The tax on debt is thus given by the probability of distress times the expected social cost of debt (via greater liquidations) in distress. In contrast to debt, increases in project scale (holding debt fixed) reduce liquidations because they increase total collateral, resulting in a subsidy for scale. This subsidy arises because an increase in project scale, holding debt fixed, must be achieved by increasing equity E_{ji}.

The global optimum accounts for international spillovers: the social cost $\tau_i^L(s)$ includes spillovers to both domestic and foreign banks. It also features a form of equal treatment: the wedges placed on subsidiary ji depend on the identity j only through the region of distress S_{ji}^D, meaning two subsidiaries with the same region of distress face the same wedges.

Finally, there is a straightforward implementation of the global optimum using an explicit quantity restriction: the requirement $\tau_{ji}^D D_{ji} + \tau_{ji}^I I_{ji} \leqslant \tau_{ji}^D D_{ji}^* + \tau_{ji}^I I_{ji}^*$, where D_{ji}^*, I_{ji}^* are set to their globally optimal values.[40] Rearranging this requirement yields $d_{ji} \leqslant |\frac{\tau_{ji}^I}{\tau_{ji}^D}| + [d_{ji}^* - |\frac{\tau_{ji}^I}{\tau_{ji}^D}|] \cdot \frac{I_{ji}^*}{I_{ji}}$, which is a leverage requirement with a surcharge based on size (that is, the right-hand side decreases in I_{ji}). A size-based surcharge is required because liquidations increase not only in the leverage d_{ij}, but also in size I_{ij} (holding fixed leverage).[41]

40. The argument follows in the same manner as in Online Appendix D.3 for the baseline model, with the nonnegative Lagrange multipliers for the bank regulatory constraints being $\kappa_{ij} = \lambda_i^0$.

41. This is in keeping with surcharges for systemically important institutions in equity capital and TLAC requirements (e.g., 12 CFR Part 252 RIN 7100–AE37).

1. *Country-Level Regulation.* We now consider the policies adopted by noncooperative country planners. Because the formal characterizations largely mirror those of the baseline model, we provide a detailed characterization in Online Appendix B.1 and focus here on the key differences and policy implications.

i. Quantity Regulation. Under noncooperative quantity regulation, optimal regulation of domestic banks follows the same formulas as in Proposition 5 but with the domestic distress costs Ω_{ii} in place of the total social cost τ_i^L. In other words, the domestic planner neglects spillovers to foreign banks, leading to underregulation of domestic banks in the forms of a tax on debt and subsidy on investment that are too low in magnitude relative to the global optimum. Regulation of domestic banks can equivalently be expressed by the quantity restriction $d_{ji} \leqslant |\frac{\Omega^I_{ji}}{\Omega^D_{ii}}| + [d^*_{ji} - |\frac{\Omega^I_{ji}}{\Omega^D_{ii}}|]\frac{I^*_{ji}}{I_{ji}}$, where D^*_{ji}, I^*_{ji} are evaluated at their noncooperative optimal values. By contrast, regulation of foreign banks is overly restrictive and ensures that foreign subsidiaries always have sufficient collateral to never be in distress, that is, $d_{ji} \leqslant d^*_i$. This reflects unequal treatment: $d^*_i < |\frac{\Omega^I_{ji}}{\Omega^D_{ii}}|$, that is the leverage requirement for foreign banks is tighter than for domestic banks, regardless of size. This combination motivates a cooperative regulatory agreement prescribing an increase in domestic bank regulation and equal regulatory treatment of foreign banks.[42]

ii. Pigouvian Tax Efficiency: In the absence of monopoly rents, noncooperative Pigouvian taxation achieves the efficient outcome in this setting, a result formalized in the following proposition.

PROPOSITION 6. *Suppose that for all i and $j \neq i$, $\frac{\partial^2 \Phi_{ij}}{\partial I^2_{ij}} = 0$. Then, the noncooperative equilibrium under Pigouvian taxation implements the taxes and allocations of Proposition 5, and so is globally efficient. There is no scope for cooperation.*

Proposition 6 states that noncooperative regulators can achieve efficiency by using Pigouvian taxes on debt and investment rather

42. Importantly, our model suggests that equal treatment means that the same social costs $\tau_i^L(s)$ are used to compute the leverage requirement for each bank based on its region of distress, but not that all banks are subject to the same leverage requirement.

than quantity restrictions such as leverage requirements.[43] Absent monopoly rents, these optimal taxes are given by their formulas in Proposition 5. This gives a foundation for thinking about the magnitude of the taxes that would need to be used by country planners in practice, since the tax on debt (investment) is given by the product of the probability of distress and the expected marginal social cost of debt (investment) in distress. Moreover, it tells us that the social cost of debt in distress is related to the total value of the banking sector that will end up in distress, in terms of aggregate debt of distressed banks, $D_i^A(s)$, and investment of distressed banks, $I_i^A(s)$. Thus, taxes and subsidies applied are particularly large in countries where the banking sector is large and distress is correlated across subsidiaries.

V.C. Liquidity Regulation

We augment the model to study liquidity regulation. Suppose that in each country, subsidiary *ij* can also invest in a liquid project, denoted by T_{ij} (treasury). This project yields 1 unit of payoff per unit of scale with certainty and is fully liquid so that the unit of payoff can be obtained at either date 1 or date 2. At date 0, the cost of undertaking both projects is $\Phi_{ij}(I_{ij}, T_{ij})$. The "net debt" $ND_{ij} = D_{ij} - T_{ij}$ is the amount that needs to be repaid using collateral-backed debt rollover or asset liquidations at date 1, leading to a liquidation rule $L_{ij}(s) = \frac{1}{h_j(s)\gamma_j(s)} \max\{ND_{ij} - d_j^*(s)I_{ij}, 0\}$ and a region of distress $S_{ij}^D = \{s \in S | ND_{ij} > d_j^*(s)I_{ij}\}$. From here, the analysis proceeds as in the baseline model, with detailed formal characterizations left to Online Appendix B.2.

1. *Globally Optimal Regulation.* Globally optimal regulation of debt and illiquid project scale is given as in Proposition 5, except that net debt ND_{ij} now determines subsidiary distress and spillovers. The key new addition is liquidity regulation, which is given by $\tau_{ji}^T = -\tau_{ji}^D$ because liquid assets and debt have equal and opposite effects on net debt. Globally optimal regulation can be expressed as a liquidity requirement $D_{ji} \leqslant T_{ji} + |\frac{\tau_{ji}^I}{\tau_{ji}^D}| I_{ji} + [D_{ji}^* - T_{ji}^* - |\frac{\tau_{ji}^I}{\tau_{ji}^D}| I_{ji}^*]$. Concretely, consider this liquidity requirement in the context of the liquidity coverage ratio

43. Intuitively, the subsidy on scale is optimal because greater stability increases the value of debt, and so increases revenue by increasing the tax that can be applied to subsidiary debt.

(LCR), which requires that banks have sufficient high-quality liquid assets to cover creditor outflows over a 30-day stress period.[44] Calculation of the LCR requires a specification of the run-off rate, that is what fraction of bank creditors' claims will be withdrawn, as well as liquidity weights assigned to different assets used to cover withdrawals. Our results imply that the globally optimal LCR assigns a run-off rate of 100%, a liquidity weight of 1 to liquid assets, and a liquidity weight $|\frac{\tau^I_{ji}}{\tau^D_{ji}}|$ to illiquid assets. Moreover, the constant on the right-hand side acts as a size-based surcharge to the liquidity requirement.

2. *Noncooperative Quantity Regulation.* Noncooperative regulators under quantity regulation again set liquid asset requirements on domestic banks to be too low, calibrating regulation accounting for domestic spillovers but neglecting foreign spillovers. They also set the requirement for foreign bank subsidiaries to be too high, imposing $D_{ji} \leqslant d^*_i I_{ji} + T_{ji}$, so that foreign subsidiaries must hold sufficient liquid assets to offset one-for-one debt D_{ji} that exceeds illiquid collateral $d^*_i I_{ji}$. In the context of LCR, our results imply that noncooperative regulators impose an LCR on foreign bank subsidiaries that assigns a run-off rate of 100%, a liquidity weight of 1 to liquid assets, and a liquidity weight d^*_i to illiquid assets. This helps us understand cooperative agreements, such as Basel III, which provide common standards for LCR and NSFR. Moreover, it helps us understand concerns that uncoordinated liquidity requirements could lead to excessive liquidity ring fencing.[45]

3. *Noncooperative Pigouvian Taxation.* Noncooperative regulators under Pigouvian taxation achieve the efficient outcome when monopoly rents are zero, employing taxes on debt, illiquid

44. Similarly, the net stable funding ratio (NSFR) provides for liquidity coverage over a longer horizon.

45. For example, a recent proposal by the U.S. Federal Reserve Board to "impose standardized liquidity requirements on the U.S. branch and agency network of a foreign banking organization" (84 FR 59032) raised concerns that the proposal would lead other countries "to implement similar requirements" and could "lead to market fragmentation," meaning that "concerns regarding liquidity risk at branches and agencies should be further discussed and evaluated at the global level by international regulatory groups before any actions are taken at the national level" (84 FR 59230).

assets, and liquid assets. Concretely, our results suggest regulators can achieve efficiency by using subsidies of liquid asset holdings, rather than by imposing liquidity requirements such as LCR.

V.D. Cross-Border Support and Resolution

We augment the model to study the possibility that subsidiaries in different countries may support one another during times of distress. In practice, this can happen in several ways: (i) bank i may use explicit guarantees of debts of its subsidiaries; (ii) bank i may structure itself for single-point-of-entry resolution (SPOE), under which the holding company, rather than operating subsidiaries, is resolved, and transfers between jurisdictions may be required to repay debts of subsidiaries;[46] and (iii) bank i could expand using branches rather than subsidiaries, in which case the foreign bank would be liable for the debts of its branches.[47]

We model cross-border support as a "transfer" or "guarantee" of $G_{ij}(s)$ from bank i to its subsidiary ij in state s, where $G_{ij}(s) < 0$ indicates the subsidiary supporting the parent.[48] It is natural to consider state-contingent transfers in the context of cross-border support. For example, in a SPOE regime, a subsidiary with modest losses would support a subsidiary with large losses by resolution of the parent holding company. We assume commitment over transfers $G_{ij}(s)$. In practice, we think of committed transfers as arising from the organizational structure of the bank at date 0, for example: (i) guarantees of subsidiary debt; (ii) establishment of SPOE resolution; or (iii) expansion via branches rather than subsidiaries.[49]

46. See Bolton and Oehmke (2019) for formal analysis of SPOE versus MPOE and Tucker (2014) for further discussion. In this section, we focus on the transfers that occur between jurisdictions as part of the resolution process (i.e., the internal resolution process), rather than on the part of the resolution process involving write-downs of the external debt of the bank holding company.

47. Although in practice branches are typically regulated by the home country, host country regulators in theory could also impose regulations, such as branch liquidity requirements (84 FR 59230 and 84 FR 59032). Nolle (2012) provides some background on organizational form for multinational banks.

48. Results in this section generalize to cases where there are incomplete markets restrictions on feasible transfers.

49. Notice that this model can be viewed as a reinterpretation of the baseline model. In the baseline model, bank i has debt at the holding company that could be rolled over using collateral or liquidations in any country. Liabilities are at the country level, but bank i can freely reallocate resources from collateral or liquidations between countries. In this sense, an alternative interpretation of

Transfers must be balanced budget, that is, $G_{ii}(s) + \int_j G_{ij}(s)dj = 0$. The subsidiary liquidation rule is $L_{ij}(s) = \frac{1}{h_j(s)\gamma_j(s)} \max\{D_{ij} - G_{ij}(s) - d_i^*(s)I_{ij}, 0\}$ and the region of distress is $S_{ij}^D = \{s \in S | D_{ij} > d_j^*(s)I_{ij} + G_{ij}(s)\}$. Online Appendix B.3 contains detailed formal analysis for this section.

1. *Global Optimum.* The key new component of globally optimal regulation is regulation of transfers between subsidiaries, given by $\tau_{ji}^G(s) = -\tau_i^L(s)\frac{1}{h_i(s)\gamma_i(s)}\mathbf{1}_{s\in S_{ji}^D}$. Relative to the private optimum, the global optimum encourages banks to transfer money out of (possibly distressed) subsidiaries in countries with low spillovers, that is, low $\tau_i^L(s)$, into distressed subsidiaries in countries with high spillovers. It can equivalently be viewed as a leverage requirement that adjusts for loss-absorbing capital, $d_{ji} - \mathbb{E}[|\frac{\tau_{ji}^G(s)}{\tau_{ji}^D}| \cdot g_{ji}(s)] \leqslant |\frac{\tau_{ji}^{iI}}{\tau_{ji}^D}| + \frac{T_{ji}^*}{I_{ji}}$.[50] Guarantees from the parent to the subsidiary in the region of distress provide support and relax the leverage requirement, whereas funds from the subsidiary to the parent tighten the requirement. Broadly speaking, the global optimum is consistent with an SPOE resolution regime, under which losses and loss-absorbing capital are shared across subsidiaries at the international level.[51]

2. *Noncooperative Quantity Regulation.* Noncooperative regulators using quantity regulation require that foreign bank subsidiaries satisfy $-G_{ji}(s) \leqslant d_i^*(s)I_{ji} - D_{ji}$ for all s, that is country planner i ensures foreign subsidiaries always have sufficient loss-absorbing capacity to never have to liquidate the domestic asset. Economically, this requirement more closely resembles a multi-point-of-entry (MPOE) resolution regime, under which loss-absorbing capital and resolution are conducted

commitment over taxes on ex post liquidations is that taxes are instead levied on the ex ante choices (SPOE versus MPOE, explicit guarantees, etc.) that lead to those ex post liquidations. Naturally, this exact analogy requires that ex ante decisions can be used to accomplish the same outcomes as ex post decisions, that is the presence of sufficiently rich instruments.

50. Where $T_{ji}^* = \tau_{ji}^D D_{ji}^* + \tau_{ji}^I I_{ji}^* + \mathbb{E}[\tau_{ji}^G(s)G_{ji}^*(s)]$.

51. For example, SPOE "may be more suitable to a firm that operates in a highly integrated manner (through, for example, centralized liquidity, trading, hedging and risk management)" (Financial Stability Board 2013, 13).

at the subsidiary, rather than at the holding company.[52] This motivates cooperative resolution, which allows for allocating losses to subsidiaries in countries with low spillovers.

3. *Noncooperative Pigouvian Taxation.* Without monopoly rents, noncooperative Pigouvian taxation implements the global optimum, with the addition of taxes $\tau_{ji}^{G}(s)$ on transfers. In practice, this Pigouvian tax could be implemented by charging an entry fee to a bank based on the organizational structure and the implied path of transfers. In particular, if a foreign bank establishes a structure that results in a future set of transfers $G_{ji}(s)$, our results say that the total fee that should be charged is $\Pr(s \in S_{ji}^{D}) \cdot \mathbb{E}[\tau_i^L(s) \frac{-G_{ji}(s)}{h_i(s)\gamma_i(s)} | s \in S_{ji}^{D}]$. An isolated subsidiary, as in Section V.A, would not generate transfers to or from its banking group, that is, $G_{ji}(s) = 0$, and would not be charged an entry fee. By contrast, a bank organizing under SPOE or expanding via a branch would expect to support or be supported by its parent in a future resolution, with an entry fee charged as above.

V.E. Bailouts and Fiscal Backstops

Fiscal backstop measures (or bailouts)—such as deposit insurance, lender of last resort (LOLR), asset purchases, and debt guarantees—may be complementary to an effective regulatory regime in safeguarding financial stability and are an additional focus of cooperative regimes.[53] We model bailouts as commitments to ex post lump-sum transfers $T_{ij}^{1}(s)$ by the government to subsidiary ij, which are paid for by raising funds from taxpayers. For example, committed transfers can arise from deposit insurance. Bailouts reduce the debt burden of subsidiary ij to $D_{ij} - T_{ij}^{1}(s)$, relaxing the collateral constraint in a state-contingent manner. Country planner i and country planner j can provide backstops

52. This is also consistent with excessive liquidity ring fencing at the branch level. For example, commentators on the standardized liquidity requirement for foreign branches noted that it "could limit the ability of foreign banking organizations to deploy funds as needed, including during times of stress" (84 FR 59230).

53. For example, see Bianchi (2016), Keister (2016), Jeanne and Korinek (2020), and Clayton and Schaab (2021) for formal work and Geithner (2016) for a policy perspective on complementarities between bailouts and regulation. See Acharya, Pierret, and Steffen (2021) for discussion and analysis of the ECB as a common (EU-wide) LOLR. See European Commision (2015) for a proposal for common deposit insurance for the EU.

to subsidiary *ij*. Online Appendix B.4 provides detailed formal analysis.

In this environment, noncooperative planners using quantity regulation also underprovide fiscal backstops to both domestic and foreign banks, not internalizing the positive spillover effects from greater financial stability to foreign banks. Moreover, a Pigouvian tax approach to regulation is not enough to achieve efficiency. The intuition is that bailouts are not priced, and so the Pigouvian tax does not appropriately capture the willingness to pay of foreign banks for bailouts. However, if planners also charge a Pigouvian tax (or fee) to banks for the bailouts they expect to receive, efficiency is restored. This might be achieved through a deposit insurance premium or a fee for ability to access the domestic LOLR.

VI. A General Framework

In this section, we study the extent to which the insights of the baseline model generalize to broader banking environments and other banking externalities and discuss limitations in its applicability. We show that in addition to whether there is a monopoly problem, the applicability of the result depends on the form of the externality, which we further explore and discuss in the context of five examples.[54] "Local" externalities that only affect domestic agents, such as spillovers to the real economy (Example 1) or spillovers to the surplus of local arbitrageurs (Example 2), can be addressed noncooperatively under Pigouvian taxation, but not under quantity regulation when foreign banks contribute to them. By contrast, "global" externalities, which also affect foreign agents, may not be well handled by Pigouvian taxation, unless they spread endogenously through the cross-border activities of banks (as with fire sales in the baseline model). In this context, we show that efficiency extends when foreign banks can also purchase domestic fire-sold assets (Example 4). However, we illustrate how efficiency breaks down with global environmental externalities (Example 3) and, drawing on this

54. Online Appendix E contains additional extensions under which qualitatively similar results hold, including allowing for global traded goods (Online Appendix E.1), local constraints on foreign bank activities (Online Appendix E.2), heterogeneous within-country agents (Online Appendix E.3), nonlinear country aggregates (Online Appendix E.4), general nonregulatory government actions (Online Appendix E.5), and preference misalignment between country planners and multinational agents (Online Appendix E.6).

example, show how efficiency also breaks down if there are unregulated international shadow banks (Example 5).

VI.A. Model

Each country $i \in [0, 1]$ has a representative multinational agent (or bank). The representative multinational agent has a vector $a_{ij} = \{a_{ij}(m)\}_{m \in M}$ of continuous and real-valued actions available in country j, where M is an indexing set and where $a_{ij}(m) \geqslant 0$.[55] The action $a_{ij}(m) = 0$ indicates not conducting activity m in country j. Multinational agents are home biased, so that domestic actions are a mass and foreign actions are a density.

We use country-level aggregates to capture spillover effects in the model. In particular, define $a_i^A(m) = a_{ii}(m) + \int_j a_{ji}(m)dj$ to be the aggregate action m in country i, with $a_i^A = \{a_i^A(m)\}$ denoting the vector of aggregates in country i. In the baseline model, the relevant aggregate for spillovers was aggregate liquidations $L_i^A(s)$ in each state s, which affected multinational banks by determining the liquidation price.

Country i multinational agents have a utility function $U_i(u_i(a_i), u_i^A(a_i, a^A))$, where $u_i(a_i) = u_{ii}(a_{ii}) + \int_j u_{ij}(a_{ij})dj$ and $u_i^A(a_i, a^A) = u_{ii}^A(a_{ii}, a_i^A) + \int_j u_{ij}^A(a_{ij}, a_j^A)dj$.[56] This preference structure provides a flexible way to add up the utility effect of activities in different countries—for example, a consumption good in each country—while ensuring sufficient continuity so that a change in foreign activities generates a utility effect proportional to the measure of those activities. Multinational agents face constraint sets $\Gamma_i(W_i, \phi_i(a_i), \phi_i^A(a_i, a^A)) \geqslant 0$, where W_i is the wealth of the multinational agents (accounting for taxes), and where $\phi_i(a_i) = \phi_{ii}(a_{ii}) + \int_j \phi_{ij}(a_{ij})dj$ and $\phi_i^A(a_i, a^A) = \phi_{ii}^A(a_{ii}, a_i^A) + \int_j \phi_{ij}^A(a_{ij}, a_j^A)dj$. Taken together, the optimization problem of country i multinational agents is

(17)
$$\max_{a_i} U_i\left(u_i(a_i), u_i^A(a_i, a^A))\right) \text{ s.t. } \Gamma_i\left(W_i, \phi_i(a_i), \phi_i^A(a_i, a^A)\right) \geqslant 0,$$

55. An example of an indexing set is $M = \{0\} \cup \{\{1\} \times S\}$, which denotes an action $a_{ij}(0)$ at date 0 and an action $a_{ij}(1, s)$ at date 1 in state s. We can impose that there are only actions $M' \subset M$ in country j by making actions $m \notin M'$ valueless.

56. Note that u_i, u_i^A can be functions in a generalized sense—for example, a vector of real numbers or a vector of functions defined over an underlying state space.

where all multinational agents take the vector a^A of aggregates as given.

VI.B. Globally Efficient and Noncooperative Policies

We first characterize the globally efficient allocation. The global planner uses a complete set of wedges $\tau_{ji}(m)$ on each action m of each multinational agent j in each country i, which are taken out of the wealth level W_i of that multinational agent and are remitted lump sum to the agent.[57]

PROPOSITION 7. *The globally efficient allocation can be decentralized by wedges*

$$\tau_{ji}(m) = -\underbrace{\Omega_{ii}(m)}_{\text{Domestic Spillovers}} - \underbrace{\int_{i'} \Omega_{i'i}(m) di'}_{\text{Foreign Spillovers}} \underbrace{\forall j}_{\text{Equal Treatment}},$$

where $\Omega_{i'i}(m) = \underbrace{\frac{\omega_{i'}}{\lambda^0_{i'}} \frac{\partial U_{i'}}{\partial u^A_{i'}} \frac{\partial u^A_{i'i}}{\partial a^A_i(m)}}_{\text{Utility Spillovers}} + \underbrace{\frac{1}{\lambda^0_{i'}} \Lambda_{i'} \frac{\partial \Gamma_{i'}}{\partial \phi^A_{i'}} \frac{\partial \phi^A_{i'i}}{\partial a^A_i(m)}}_{\text{Constraint Set Spillovers}}$ *is the spillover effect on country i' multinational agents from an increase in $a^A_i(m)$, where $\Lambda_{i'}$ is the Lagrange multiplier on the constraint set of country i' agents and $\lambda^0_{i'} \equiv \Lambda_{i'} \frac{\partial \Gamma_{i'}}{\partial W_{i'}}$ is the marginal value of wealth to country i' multinational agents.*

Globally optimal policy in the general model features the same two core features as the baseline model. First, globally optimal policy enforces equal treatment of foreign agents, so they are able to enjoy equally the benefits of cross-border activities. Second, globally optimal policy accounts for both domestic and foreign spillovers. There are two forms of spillovers in the general model that are reflected in $\Omega_{i'i}(m)$. The first set of spillovers is direct utility spillovers, a leading example of which is spillovers from banking activities into the real economy. The second of spillovers is constraint set spillovers, a leading example of which is fire sale externalities.

1. *Noncooperative Quantity Regulation.* The inefficiencies of noncooperative quantity regulation are qualitatively similar

57. Any required lump-sum transfers between countries are also done out of this wealth.

to those identified in Proposition 2, and we leave formal characterization to Online Appendix C. Noncooperative quantity regulation neglects international spillovers and results in unequal treatment, with foreign agent activities allowed only to the extent they benefit the domestic economy. Moreover, we show that noncooperative quantity regulation is generically inefficient in settings with externalities arising from cross-border activities.

2. *Noncooperative Pigouvian Taxation.* The efficiency of noncooperative Pigouvian taxation applies in the general model under two conditions. The first is a similar notion of no monopoly rents, which carries the same intuition and is formalized in the Online Appendix.[58] Second, it requires the following assumption on how foreign aggregates can affect a domestic agent.

ASSUMPTION 1. *For all i and $j \neq i$, u_{ij}^A and ϕ_{ij}^A are homogeneous of degree 1 in a_{ij}, holding a_j^A fixed. That is, $u_{ij}^A(\beta a_{ij}, a_j^A) = \beta u_{ij}^A(a_{ij}, a_j^A)$ and $\phi_{ij}^A(\beta a_{ij}, a_j^A) = \beta \phi_{ij}^A(a_{ij}, a_j^A)$.*

Assumption 1 states that domestic agents' exposure to aggregates in a foreign country scales with their activities in that foreign country.[59] For example, in the case where action m has a local price $\gamma_j(a_j^A)$ attached to it, we obtain a linear form $\gamma_j(a_j^A)a_{ij}(m)$, which satisfies Assumption 1, as with fire sales. Notice that homogeneity of degree 1 does not restrict the form of the pricing function γ_j, which may be nonlinear (as in the baseline model). Moreover, although Assumption 1 restricts the form of cross-border externalities, it places no restrictions on the form of domestic externalities affecting domestic agents. It also allows for multiple externalities, for example fire sales of multiple assets combined with spillovers to the real economy.

To understand the role of Assumption 1, we decompose the gap between the wedge that is set by the global planner and the Pigouvian tax set by country planner i. For expositional

58. Note that the requirement of no monopoly rents implies that our theory does not provide a solution to terms of trade manipulation, given that the monopolist distortion is similar to terms of trade manipulation. More subtly, it implies that Pigouvian taxation may have trouble addressing problems of domestic market power of foreign multinational agents. This is because when a multinational agent earns monopoly rents in a country, the country planner may in turn gain some monopoly power over it.

59. Assumption 1 requires linear scaling because the Pigouvian tax is linear.

simplicity, we illustrate the decomposition for utility spillovers alone,[60] which is given by

(18)
$$\tau_{ji}(m) - \tau_{i,ji}(m) = \int_{i'} \frac{1}{\lambda^0_{i'}} \omega_{i'} \frac{\partial U_{i'}}{\partial u^A_{i'}} \left(\underbrace{\frac{\partial}{\partial a^A_i(m)} \left[\frac{\partial u^A_{i'i}}{\partial a_{i'i}} a_{i'i} \right]}_{\text{Tax Revenue Derivative}} - \underbrace{\frac{\partial u^A_{i'i}}{\partial a^A_i(m)}}_{\text{Externality}} \right) di',$$

when monopoly rents are zero. This gap is determined by the gap between the true externality effect on foreign agents, $\frac{\partial u^A_{i'i}}{\partial a^A_i(m)}$, and the change in tax revenue collected from foreign agents, $\frac{\partial}{\partial a^A_i(m)} \left(\frac{\partial u^A_{i'i}}{\partial a_{i'i}} a_{i'i} \right)$, that arises because changes in domestic aggregates affect the willingness to pay of foreign agents for domestic activities. Homogeneity of degree 1 (Assumption 1) implies that the tax revenue derivative and externality effect are precisely equal, $\frac{\partial u^A_{i'i}}{\partial a_{i'i}} a_{i'i} = u^A_{i'i}$, leading to efficiency.

Assumption 1 gives rise to a natural classification of types of externalities into local and global externalities, which we now discuss.

VI.C. Pigouvian Efficiency under Local Externalities

We first examine the efficiency of Pigouvian taxation under a class of local externalities. Local externalities arise when the domestic aggregates a^A_i only affect domestic multinational agents.[61] For example, local externalities might include spillovers from the financial sector to the real economy of that country or costs to the domestic deposit insurance entity. Under quantity regulation, local externalities result in unequal treatment of foreign banks. By contrast, under Pigouvian taxation, because a^A_i does not affect foreign agents, under the decomposition of equation (18) we have $\frac{\partial u^A_{i'i}}{\partial a^A_i(m)} = \frac{\partial}{\partial a^A_i(m)} (\frac{\partial u^A_{i'i}}{\partial a_{i'i}} a_{i'i}) = 0$. A Pigouvian tax approach results in the efficient outcome, provided monopoly rents are zero, for the entire class of local externalities problems, even though foreign agents can contribute to these externalities

60. Including constraint set spillovers simply adds a second and analogous term to the decomposition.

61. Of course, actions a_{ji} can still appear in utility functions and constraints of country j multinational agents.

through their activities. Cooperation is not required. We can state this result formally as follows.

COROLLARY 1. *Suppose that there are only local externalities, that is $u_{ij}^{A} = \phi_{ij}^{A} = 0$ for all i and $j \neq i$. Then absent monopoly rents, the noncooperative equilibrium under Pigouvian taxation is globally efficient.*

Corollary 1 is a corollary of Proposition 21 in Online Appendix C, which shows Pigouvian efficiency when Assumption 1 holds and there are no monopoly rents. Corollary 1 follows because $u_{ij}^{A} = \phi_{ij}^{A} = 0$ for $j \neq i$ trivially satisfies Assumption 1. We now provide two examples that incorporate local externalities into the baseline model and show that Pigouvian tax efficiency continues to hold.

Example 1: Real Economy Spillovers: Suppose that banking activities have spillovers into the domestic economy, for example changes in credit available to SMEs. We model these spillovers in the baseline model as an additive term $u_i^A(I_i^A, L_i^A)$ (where $I_i^A = I_{ii} + \int_j I_{ji} dj$) in the utility of the representative agent, so that social welfare includes both bank consumption and the real economy spillovers. This additional term only affects domestic agents, not foreign ones, meaning that it is fully internalized by the domestic planner in the domestic spillover. There is no change in foreign spillovers, meaning Pigouvian efficiency holds by the same logic as the baseline model. In the general framework of this section, this term satisfies Assumption 1, which places no restrictions on the form of domestic spillovers.

In Online Appendix D.5, we discuss the implications of real economy spillovers (and Example 2) for noncooperative quantity regulation. In contrast to the baseline model, noncooperative quantity regulation can lead to underregulation of foreign banks if the benefit of foreign banks to the domestic economy exceeds their cost in terms of domestic fire sale spillovers. However, the domestic planner still neglects the value of foreign banks to foreigners and continues to underregulate domestic banks and impose unequal treatment.

Example 2: Arbitrageur Welfare: Suppose that in the baseline model, arbitrageurs in country i have utility $\theta_i w_i^A + E[c_i^A]$, where $\theta_i > 0$ and where w_i^A is date 0 wealth of arbitrageurs. Arbitrageurs cannot borrow or save. Country i social welfare is $E[c_i] + \omega_i^A[\theta_i w_i^A + E[c_i^A]]$ for Pareto weight ω_i, with

$c_i^A(s) = \mathscr{F}_i(L_i^A(s), s) - \gamma_i(s) L_i^A(s)$. This is simply another form of local spillover, satisfying Assumption 1, so that Pigouvian tax efficiency holds. Given a Pareto-efficient allocation has $\omega_i^A \theta_i = \lambda_i^0$ (equalizing marginal value of wealth across agents), the additional spillover is

$$\Omega_{ii}^A(s) = \frac{1}{\lambda_i^0} \omega_i^A \frac{\partial c_i^A(s)}{\partial L_i^A(s)} = -\frac{1}{\theta_i} \frac{\partial \gamma_i(s)}{\partial L_i^A(s)} L_i^A(s),$$

that is fire sales have a positive spillover to arbitrageurs. This positive spillover reduces the magnitude of the liquidation wedge, but as in Example 1, this is only a change in spillovers to domestic agents. Pigouvian taxation is still efficient by the same logic as the baseline model, which is the limiting case $\theta_i \to +\infty$. Assumption 1 again holds, as in Example 1.[62]

VI.D. Pigouvian Efficiency under Global Externalities

We next discuss the efficiency of Pigouvian taxation under a class of global externalities. Global externalities are externalities that also affect foreign agents—the domestic aggregates a_i^A appear in the utility functions or constraint sets of foreign agents.

The fire sale externality of the baseline model was a form of global externality: the domestic aggregate $L_i^A(s)$ appeared in the constraint sets of foreign banks through the liquidation price $\gamma_i(s)$. However, this global pecuniary externality satisfied Assumption 1: foreign banks' exposure to the domestic externality scaled linearly with their domestic activities. As a result, even though the externality took on a global dimension, its endogenous spread through banks' cross-border activities allowed the domestic planner to internalize its global effect through revenue collections. This suggests that Pigouvian efficiency extends to a broader class of pecuniary externality problems resulting from domestic prices appearing in the constraints of foreign banks. For example, Online Appendix D.2 studies a case where local investment has to be undertaken using a local capital good, with a local price. Whereas country planners under quantity regulation

62. As is usual in constrained-efficient planning problems with fire sales, an increase in regulation that reduced liquidations would make arbitrageurs worse off. This implies optimal policy would combine a Pigouvian tax with lump-sum transfers from banks to arbitrageurs at date 0. This is true under both the globally efficient and Pigouvian regimes.

engage in protectionism to shield their own banks from competition, under Pigouvian taxation they achieve the efficient outcome.

Example 3: Climate Change. To help understand the limitations implied by Assumption 1, we start with a simple example unrelated to banking: climate change. Consider an economy with a single activity in each country, "production" a_{ij}. Production benefits agents but produces carbon emissions, so country i welfare is $u_{ii}(a_{ii}) + \int_j u_{ij}(a_{ij})dj + W_i - \int_j a_j^A dj$. It is intuitive why the revenue collection motive fails to account for climate change spillovers: the spillover $\int_j a_j^A dj$ is separable in utility. Aggregate carbon emissions a_i^A from country i therefore do not affect the marginal value to bank j of domestic production, a_{ji}, and hence do not change revenue collected. Formally, observe that the spillover does not satisfy Assumption 1. To see the failure of noncooperative Pigouvian taxation, in the decomposition in equation (18) we have a spillover effect $\frac{\partial u_{i'i}^A}{\partial a_i^A(m)} = -1$. Because climate change is separable in utility, we have $\frac{\partial}{\partial a_i^A(m)}(\frac{\partial u_{i'i}^A}{\partial a_{i'i}} a_{i'i}) = 0$, that is, it does not affect tax revenues. As a result, noncooperative Pigouvian taxation does not account at all for climate change.

Example 4: Global Banks and Arbitrage. In the baseline model, foreign banks were not able to purchase the domestic asset. In practice, international banks can potentially buy domestic fire-sold assets and support the domestic price, rather than depress it. We extend our baseline model to allow banks to buy and sell assets and show that our main result on Pigouvian efficiency still holds, with the same intuition. The spillover effects generated by asset purchases and the spillover effects onto purchasing banks are the same as those of asset sales but with opposite signs.

Formally, banks can purchase assets at date 1, denoted $P_{ij}(s) \geqslant 0$. Purchased assets yield a final payoff of $F_{ij}(P_{ij}(s), s)$ at date 2, with $F_{ij}'(0, s) \leqslant 1 + r_{ij}$ so that the marginal return to purchased assets is no larger than the marginal return on retained assets.[63] Because the cost to purchases is $\gamma_j(s)P_{ij}(s)$, and asset purchases provide collateral value $(1 - h_j(s))\gamma_j(s)P_{ij}(s)$, the bank must

63. This means that banks never find it optimal to buy assets in country j at the same time they are selling assets in country j, that is $P_{ij}(s) > 0$ only if $L_{ij}(s) = 0$.

raise the difference $h_j(s)\gamma_j(s)P_{ij}(s)$ either by using its existing assets as collateral or by selling its existing assets. In other words, the modified amount that the bank must finance out of existing assets is $\hat{D}_i = D_i + h_i(s)\gamma_i(s)P_{ii}(s) + \int_j h_j(s)\gamma_j(s)P_{ij}(s)dj$, which now appears on the left-hand side of the collateral constraint equation (3). Thus, the collateral constraint also restricts asset purchases. Final bank consumption is $\hat{c}_i(s) = c_i(s) + F_{ii}(P_{ii}(s), s) - \gamma_i(s)P_{ii}(s) + \int_j [F_{ij}(P_{ij}(s), s) - \gamma_j(s)P_{ij}(s)]dj$, which accounts for gains from asset purchases. Finally, total asset purchases in country i are $L_i^A(s) + P_{ii}(s) + \int_j P_{ji}(s)dj$, which by market clearing must equal liquidations.

From here, Proposition 2 follows the same general form up to two changes. First, the new wedge on asset purchases is $\tau_{ij}^P(s) = -\tau_{ij}^L(s)$, because asset purchases generate the same externality as asset liquidations but with opposite sign. Second, the spillover effect onto bank i' is given by the same equation as $\Omega_{i'i}(s)$ in Proposition 2, provided we simply define $L_{i'i}(s) = -P_{i'i}(s)$ for banks that purchase, rather than sell, assets.[64] Unsurprisingly, Pigouvian efficiency continues to hold in this setting, absent monopoly rents, which requires $\frac{\partial^2 F_{ij}}{\partial P_{ij}^2} = 0$.

Finally, relating back to the general model, notice that asset purchases appear in the collateral constraint in the same form as asset sales (but with opposite sign) and satisfy Assumption 1. This reaffirms how Pigouvian efficiency continues to hold in this example.

Example 5: Shadow Banks as a Global Externality. Our results so far have assumed all cross-border agents are regulated. In this example, we show a key limitation to our main result: the presence of shadow banks, which cannot be regulated by the global or country planner, can lead to a breakdown of Pigouvian efficiency even if planners assign welfare weights of zero to shadow banks. One important practical implication

64. That is to say, for a bank that purchases assets, the spillover is given by

$$\Omega_{i'i}(s) = \underbrace{\frac{\partial \gamma_i(s)}{\partial L_i^A(s)}}_{\text{Price Impact}} \Bigg[\underbrace{-\frac{\lambda_{i'}^1(s)}{\lambda_{i'}^0} P_{i'i}(s)}_{\text{Distributive Externality}} \underbrace{+\frac{\Lambda_{i'}^1(s)}{\lambda_{i'}^0}\big(-h_i(s)P_{i'i}(s) + (1-h_j(s))R_i(s)I_{i'i}\big)}_{\text{Collateral Externality}} \Bigg].$$

of this section is that Pigouvian taxation is an efficient method of regulating previously unregulated intermediaries.

To illustrate the limitation, suppose that instead of local arbitrageurs there is an unregulated global financial intermediary responsible for arbitrage. The global bank has nonseparable technology across countries, $\mathscr{F}^G(F^G(s), s)$ with $F^G(s) = \int_i F_i^G(L_i^G(s), s)di$,[65] so that its asset demand solves the system of equations $\gamma_i(s) = \frac{\partial \mathscr{F}^G(s)}{\partial F^G(s)} \frac{\partial F_i^G(s)}{\partial L_i^G(s)}$. Nonseparable technology means that liquidations in country i affect the price in country k, that is, $\frac{\partial \gamma_k(s)}{\partial L_i^G(s)} = \frac{\partial^2 \mathscr{F}^G(s)}{\partial F^G(s)^2} \frac{\partial F_i^G}{\partial L_i^G(s)} \frac{\partial F_k^G}{\partial L_k^G(s)}$. As a result, the globally optimal wedges on liquidations (with a welfare weight of zero on the global arbitrageur) are

$$\tau_{ji}^L(s) = \underbrace{-\Omega_{ii}(s) - \int_{i'} \Omega_{i'i}(s)di'}_{\text{Baseline Model Spillovers}}$$
$$+ \underbrace{\frac{\left(\frac{\partial^2 \mathscr{F}^G(s)}{\partial F^G(s)^2}\right)}{\left(\frac{\partial \mathscr{F}^G(s)}{\partial F^G(s)}\right)} \frac{\partial F_i^G}{\partial L_i^G(s)} \int_k \left[-\Omega_{kk}(s) - \int_{k'} \Omega_{k'k}(s)dk'\right]dk}_{\text{Shadow Banking Spillovers}}.$$

Under noncooperative Pigouvian taxation, country planners account for the set of baseline model spillovers but neglect the shadow banking spillovers, which arise from nonseparable technology. Intuitively, although liquidations in country i reduce prices in other countries through shadow banking, the domestic planner does not have taxes for foreign bank activities in foreign countries and cannot internalize these spillovers. Conversely, the domestic planner continues to properly internalize the spillovers resulting from the domestic liquidation price, where taxes do apply. To see how this example violates Assumption 1, the value of asset liquidations as $\gamma_j(s)L_{ij}(s)$ is now determined by two

65. Note that the results of Example 4 continue to hold in its environment with nonseparable technology $\mathscr{F}_i(F_{ii}(P_{ii}(s), s) + \int_j F_{ij}(P_{ij}(s), s), s)$, and that the key difference in this example is regulatory status and not nonseparability (nonseparable technology does not violate absence of monopoly rents, which requires that $\frac{\partial^2 F_{ij}(s)}{\partial P_{ij}(s)^2} = 0$). Conversely if technology is separable, then this model is equivalent to the baseline model, with local arbitrageurs reinterpreted as a global arbitrageur with separable technology.

functions: (i) $\varphi_{ij}^1(s) = \frac{\partial F_j^G(L_j^G(s),s)}{\partial L_j^G(s)} L_{ij}(s)$, which is the same function used in the baseline model with local arbitrageurs and satisfies Assumption 1; and (ii) $\varphi_{ij}^2(s) = F_j^G(L_j^G(s), s)$, which captures nonseparability and does not satisfy Assumption 1.[66] Notice that $\varphi_{ij}^2(s)$ is in fact of the same general form as the climate change spillover of Example 3: the failure of efficiency, in that the shadow banking spillover generates spillovers in foreign countries that are not internalized by revenue collection, is actually a close cousin of the climate change example.

This example showcases the difficulty that unregulated agents pose for Pigouvian efficiency, since cross-border spillovers via unregulated agents are not internalized through revenue collection from these agents.[67] One concrete implication is that Pigouvian taxation provides an efficient method of regulating previously unregulated shadow banks or other cross-border capital flows. Our theory thus suggests a novel synergy between regulation of banks and shadow banks (or unregulated capital flows). By applying Pigouvian taxes to manage unregulated capital flows, the domestic regulator also improves the efficiency of domestic macroprudential regulation, internalizing spillovers to foreign agents through revenue collection.

66. For full clarity, in this case we have $\varphi_i^1(s) = \frac{\partial F_i^G(L_i^G(s),s)}{\partial L_i^G(s)} L_{ii}(s) + \int_j \frac{\partial F_j^G(L_j^G(s),s)}{\partial L_j^G(s)} L_{ij}(s)dj$ and $\varphi_i^2(s) = \int_j F_j^G(L_j^G(s), s)dj$, so that we have

$$\begin{aligned} \frac{\partial \mathscr{F}^G(\varphi_i^2(s), s)}{\partial F^G(s)} \cdot \varphi_i^1(s) = {} & \frac{\partial \mathscr{F}^G(\varphi_i^2(s), s)}{\partial F^G(s)} \frac{\partial F_i^G(L_i^G(s), s)}{\partial L_i^G(s)} L_{ii}(s) \\ & + \int_j \frac{\partial \mathscr{F}^G(\varphi_i^2(s), s)}{\partial F^G(s)} \frac{\partial F_j^G(L_j^G(s), s)}{\partial L_j^G(s)} L_{ij}(s)dj \\ & = \gamma_i(s)L_{ii}(s) + \int_j \gamma_j(s)L_{ij}(s)dj, \end{aligned}$$

with similar functions used for defining collateral values.

67. Importantly, this needs a caveat. If another multinational agent is subject to externalities but conducts activities that do not generate externalities, Proposition 7 implies this agent is not regulated in equilibrium and the Pigouvian tax set is 0. This draws an important distinction between an agent who is unregulated in equilibrium versus one who cannot be regulated.

VII. Conclusion

We study a model of cross-border banking, in which endogenous cross-border propagation of fire sales generates international financial stability spillovers. Our main and most surprising normative contribution is to show that noncooperative national governments using revenue-generating Pigouvian taxes can implement the globally efficient allocation, eliminating the need for international cooperation. The motivation to collect revenues from foreign banks enables the domestic government to internalize the effects of domestic regulation and domestic fire sales on the value of foreign banks to foreigners, which would otherwise be neglected by the domestic government when designing revenue-neutral regulation. From a policy perspective, this suggests that giving a more prominent role to revenue-generating Pigouvian policies in the macroprudential regime may be desirable. By doing so, policy makers may be able to reduce the need for cooperative regulatory agreements and avoid the inherent difficulties of cooperation.

An important property of our model is that noncooperative governments employing taxes do not engage in a counterproductive race to the bottom, despite the motivation to collect tax revenue. However, our model focuses on bank externality regulation and does not address broader motivations for taxation such as financing public good expenditures. Cooperation over taxation for public financing is also an important and ongoing debate. An interesting direction for future research would be to study whether the forces identified herein also have implications for cooperation in these settings.

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Supplementary Material

An Online Appendix for this article can be found at *The Quarterly Journal of Economics* online.

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