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Collateral-Motivated Financial Innovation

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Abstract

This paper proposes a collateral view of financial innovation: Many innovations are partly motivated by alleviating collateral constraints for trading (speculation or hedging). We analyze a model of investors with disagreement. The trading need motivates them to introduce derivatives, which are endogenously determined in equilibrium. In the presence of a collateral friction in cross-netting, the derivative that isolates the variable with disagreement is "optimal" in the sense that alternative derivatives cannot generate any trading. Financial intermediation arises as a way to mitigate this collateral friction, leading to asset-backed securities and tranching. This view of financial innovation is distinct from "completing markets": We demonstrate that in an economy with N states, investors may prefer to introduce more than N securities, and yet still don't complete the markets. More broadly, this collateral view highlights the common theme behind a variety of innovations with strikingly different appearances: the invention of securities (e.g., swaps), legal entities (e.g., special purpose vehicles), legal practice (e.g., the superseniority for derivatives), as well as the efforts in improving cross-netting.

JEL Classification Numbers: G11, G23.
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1 Introduction

The past half-century has witnessed a tremendous amount of financial innovations. What are the motives behind them? Existing theories emphasize the role of risk sharing (e.g., Allen and Gale (1994)), transaction costs and regulatory constraints (Benston and Smith (1976), Miller (1986)), and information asymmetry (Gorton and Pennacchi (1990), DeMarzo and Duffie (1999)).

This paper proposes an alternative view: Many successful financial innovations are partly motivated by mitigating collateral (or margin) constraints for trading. Suppose, for example, two traders have different expectations for the future value of a security—say, a corporate bond. If their disagreement is about the company's default probability, rather than the future movements of riskless interest rates, then it is natural that the traders prefer to take positions in credit default swaps (CDSs), rather than the corporate bond. This is because by isolating the default probability, the variable that traders are interested in betting on, a CDS on the underlying corporation requires the least collateral and is efficient in facilitating their speculation.[1] This collateral motivation is not limited to speculative trading: Suppose, for instance, a risk manager needs to hedge a certain exposure, and can trade two financial instruments with the same hedging quality. To the extent that raising capital is costly, the risk manager clearly has a preference for the instrument with a lower collateral requirement.

Motivated by the above intuition, we analyze an equilibrium model of investors with disagreement about a portion of the cash flow from an asset. The disagreement motivates investors to trade this asset, and possibly to introduce new derivatives to facilitate their trading. Casual intuition suggests that investors would introduce derivatives that are linked to the disagreement. However, the impact of this innovation on other markets is far less clear. Would investors try to complete markets? Which markets would thrive, and which would disappear? What is the notion

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[1] A vivid example is documented in Michael Lewis's book *Big Short*. During 2004–2006, a number of investors were convinced that the subprime mortgage market would soon collapse, and wanted to bet on it. However, they found that existing instruments (e.g., stocks of home building companies) can offer only an "indirect" bet. The book tells a detailed story of how those investors push investment banks to create the market of CDS contracts on subprime mortgage bonds, which provides a more "direct" bet on the subprime mortgage market.

of "optimal" innovation in this context?

To understand these issues, we analyze a model in which investors need to back up their promises (e.g., debt) by collateral. If an investor defaults on his promise, his counterparty can seize the collateral and the defaulting investor faces no further penalty.[2] Consider first a case with a perfect collateral procedure: an investor can use any part of his portfolio as collateral. For convenience, we refer to it as *portfolio margin*. It is easy to see that the collateral constraint under portfolio margin is equivalent to a nonnegative wealth constraint. Moreover, if investors introduce financial assets to complete markets, the resulting equilibrium is Pareto optimal. This case highlights the benefit of market completeness but does not have sharp predictions on financial innovation.

Our main analysis is focused on a collateral friction. For example, if the returns of two assets offset each other, then, under portfolio margin, the collateral requirement for the portfolio is reduced due to cross-netting. In practice, however, this cross-asset-netting is far from perfect. For instance, if one asset in the portfolio is exchange-traded, while the other is over-the-counter or traded on a different exchange, then the investor has to post collateral for both assets separately, even if these two positions largely offset each other. Moreover, it may be difficult or too costly for a dealer to precisely estimate the correlation among securities to determine the collateral for the whole portfolio. Or, a trader may prefer not to reveal his whole portfolio to his dealer and thus has multiple dealers, which is a common practice among hedge funds. Finally, different parts of the portfolio may be governed by different jurisdictions, and regulations may also impose various constraints on collateralization, making cross-netting imperfect.

Our key assumption, motivated by these frictions, is that investors have to post collateral for each security in their portfolios separately, which we refer to as *individual security margin*. The essential point of this assumption is that cross-asset-netting is imperfect rather than impossible. Our model's main implications are the following.

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[2]This lack of further penalty assumption is perhaps most suitable for the case of security trading, where many positions are set up for hedging, speculation, or short-term financing purposes. When an investor defaults, the top priority for his counterparties is perhaps to get compensated quickly to reestablish those positions with other investors, rather than going through a lengthy bankruptcy procedure to liquidate the defaulting investor's other assets.

First, this collateral friction determines the financial innovation in equilibrium. Intuitively, due to the collateral friction, investors prefer to trade a derivative that isolates the portion of the cash flow with disagreement, rather than trading the underlying asset. This is because the cash flow from the underlying asset has two portions, but investors are only interested in trading one of them. To the extent that the "unwanted" portion, the portion without disagreement, increases the collateral requirement for trading the underlying asset, it makes the underlying asset less appealing than the derivative. Consequently, the derivative that completely carves out the unwanted cash flow is "optimal" in the sense that its existence would drive out any other derivative markets: if one introduced any other derivatives, those markets would not generate any trading.

Second, due to the high collateral requirement for the underlying asset, its price is lower than that of its replicating portfolio. This price difference, the so-called basis, reflects the shadow value of collateral. This result is similar to that in Garleanu and Pedersen (2011), where financial contracts and collateral requirements are exogenous. Our analysis endogenizes both and shows that it is not a coincidence that derivatives are more collateral efficient than their underlying assets—this is precisely the motivation for designing those derivatives. Moreover, our model shows that the basis increases upon a positive supply shock to the underlying asset (e.g., a failing institution selling a large amount of the underlying asset), and this impact is stronger for assets with more volatile unwanted cash flows.

Third, the collateral friction gives rise to a role for financial intermediation. As noted earlier, due to the friction in cross-netting, the price of the underlying asset is lower than that of its replicating portfolio. Hence, institutions with more efficient cross-netting technologies can provide services that investors find valuable. In particular, intermediaries can acquire the underlying asset and use it as collateral to issue asset-backed securities, and tranch the underlying cash flows to satisfy the needs of each group of investors. In equilibrium, intermediaries' demand for the underlying asset pushes up its price and reduces the basis.

Fourth, this collateral motivation is distinct from the traditional intuition on completing markets. We demonstrate that in an economy with N states, investors may choose to introduce more

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than N securities, and yet, markets are still incomplete. Suppose two investors disagree on the probabilities of two states but agree on the probabilities of the rest of the $N-2$ states. In the presence of the cross-netting friction, they will introduce a security to isolate those two states, even if a portfolio of existing instruments can replicate this security. Similarly, other investors may want to introduce securities to isolate states that they disagree on. There are certainly more than N possible securities. For example, for bets on two states alone, there are $\binom{N}{2} = N(N-1)/2$ possibilities. This intuition perhaps partly explains the prevalence of similar, sometimes apparently redundant, securities. For example, on the Chicago Board of Exchange, there are over 800 one-month options on the S&P 500 index with various strike prices. This is, of course, also consistent with the traditional view of completing markets. But this traditional view does not explain the need to introduce an option, whose payoff is simply a linear combination of a few other options.

Finally, and more broadly, this collateral view of financial innovation highlights the common theme behind a variety of innovations with strikingly different appearances, such as the invention of new securities, legal entities, legal practice, as well as policy and regulation changes. As noted earlier, many derivatives, such as swaps, allow investors to get large exposures with very little collateral. Another example of collateral-motivated innovation is the emerging legal practice of the so-called superseniority of derivatives. When an institution goes bankrupt, its derivative counter-parties can simply seize the collateral posted in the transactions, instead of going through a lengthy and costly bankruptcy procedure.[3] In the context of our analysis, this practice can also be viewed as carving unwanted cash flows out of derivative transactions: Suppose an investor enters an interest rate swap to hedge interest rate risk. Without superseniority, even if his counterparty posts a large amount of collateral, the investor is still not well protected since he would have to go through the bankruptcy procedure when his counterparty defaults. With superseniority, however, the investor can immediately seize the collateral upon default, and so can be better protected even by a smaller

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[3]This exceptional treatment accorded derivatives and repos in bankruptcy is recent. It was formalized by the introduction of "Act to Amend Title 11, United States Code, to Correct Technical Errors, and to Clarify and Make Substantive Changes, with Respect to Securities and Commodities" to the bankruptcy code as of July 27, 1982 (Pub. L. 97-222 (HR 4935)). There have been numerous revisions over the years. A recent example is the Financial Netting Improvements Act of 2006 (Pub. L. 109-390).

amount of collateral. From this investor's perspective, his counterparty's assets, apart from the posted collateral, are unwanted cash flows, which are carved out of the swap transaction by super-seniority. Financial innovations may also take the form of legal entities, such as special purpose vehicles (SPVs) in securitization. We can view SPVs as part of the aforementioned cross-netting technology that allows financial intermediaries to issue asset-backed securities. Note also that the collateral friction in our model arises from the restriction in cross-netting. Hence, one can view the continuing efforts by regulators and market participants in improving the cross-netting procedure, from the International Swap and Derivative Association (ISDA) Master Agreement to numerous rules and regulations by exchanges and broker-dealers, as a form of collateral-motivated financial innovation. Their goal is simply to satisfy the demand from market participants to alleviate their collateral constraints.

2   Literature Review

There is an extensive literature on financial innovation. Recent surveys, such as Allen and Gale (1994) and Duffie and Rahi (1995), emphasize the risk-sharing aspect of innovation; Tufano (2003) also discusses the roles of regulatory constraints, agency concerns, transaction costs and technology. More recent studies explore the role of rent seeking (Biais, Rochet, and Woolley (2010)) and neglected risk (Gennaioli, Shleifer, and Vishny (2011)). These studies generally abstract away from collateral constraint, which is the focus of this paper. One exception is Santos and Scheinkman (2001), which analyzes a model where exchanges set margin levels to screen traders with different credit qualities. Also related are the studies that analyze the impact of financial innovation in models with heterogeneous beliefs or preferences (Zapatero (1998), Bhamra and Uppal (2009), Simsek (2012), Banerjee and Graveline (2011)). These studies focus on the insight that innovation leads to more speculation and higher volatility, while our analysis focuses on the collateral friction and its implications on endogenous financial innovation and intermediation.

The role of collateral has been analyzed in various contexts, such as the macroeconomy (e.g., Kiyotaki and Moore (1997)), corporate debt capacity (e.g., Rampini and Viswanathan (2010)),

arbitrageurs' portfolio choices (e.g., Liu and Longstaff (2004)), and asset prices and welfare (Basak and Croitoru (2000), Gromb and Vayanos (2002)). Our analysis of collateral requirement builds on Geanakoplos (1997, 2003), which has been extended to study leverage cycle (Fostel and Geanakoplos (2008), Geanakoplos (2009)), speculative bubble (Simsek (2011)), and debt maturity (He and Xiong (2010)). Our analysis of leverage is also related to the studies of financial products that help constrained investors to take leverage (Frazzini and Pedersen (2011), Jiang and Yan (2012)). Finally, our paper is related to Garleanu and Pedersen (2011), who analyze a model with exogenous market structure and collateral requirements. Our paper focuses on the endogenous financial innovation, collateral requirements, as well as financial intermediation.

The rest of the paper is as follows. Section 3 presents a model of collateral-motivated financial innovation. Section 4 analyzes the role of financial intermediaries. Section 5 highlights the difference between the collateral motivation and the traditional intuition of completing markets. Section 6 includes some further discussions, and Section 7 concludes. All proofs are in the Appendix.

3 A Model of Financial Innovation

We consider a two-period economy, $t = 0, 1$, that is populated by a continuum of investors. The total population is normalized to 1. All investors are risk neutral, and they make investment decisions at $t = 0$ to maximize their expected wealth at $t = 1$. There is a riskless storage technology with a return of 0. All investors have the same endowment, and the aggregate endowment is e ($e \geq 0$) dollars in cash and β ($\beta \geq 0$) units of asset A, which is a claim to a random cash flow $\widetilde{A}$ at $t = 1$. Investors have different beliefs about the distribution of $\widetilde{A}$, and the disagreement is focused on a portion of it. More precisely, we denote the cash flow as

$$\widetilde{A} = \widetilde{V} + \widetilde{U}, \tag{1}$$

and investors disagree on the distribution of $\widetilde{V}$ but share the same belief about the distribution of $\widetilde{U}$, which is independent of $\widetilde{V}$.

To highlight the basic intuition, we consider first the case with two types of investors (the case

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with more types of investors is in Section 5). We refer to these two types of investors as optimists o and pessimists p. Investor i, $i \in \{o, p\}$, believes the distribution of $\widetilde{V}$ is

$$\widetilde{V} = \begin{cases} V_u & \text{with a probability } h_i, \\ V_d & \text{otherwise,} \end{cases} \tag{2}$$

with $V_u > V_d$ and $h_o > h_p$. We use α_o and α_p to denote the population sizes of optimists and pessimists, respectively, and $\alpha_o + \alpha_p = 1$. Without loss of generality, we assume $\widetilde{U}$ has a mean of zero. For simplicity, we assume $\widetilde{U}$ has a uniform distribution on $[-\Delta, \Delta]$, with $\Delta > 0$ and $V_d - \Delta \geq 0$, and these assumptions are not essential for our main results.

The disagreement among investors motivates them to trade, and this trading need may also induce financial innovation. In this section, we assume that investors can directly design derivatives, and postpone the analysis of financial intermediation to Section 4. We assume that investors can introduce any financial derivatives if they prefer. A generic derivative is a claim to a cash flow $\widetilde{K}$ at $t = 1$, which can be any function of $\widetilde{V}$ and $\widetilde{U}$. We use $\mathcal{H}$ to denote the set of all possible derivatives.[4] For convenience, if a derivative is a claim to a random cash flow $\widetilde{K}$, we refer to it as "asset K."

3.1   Benchmark Case: Portfolio Margin

Following Geanakoplos (1997, 2003), we assume that when an investor defaults, his counterparty can seize only the collateral posted for this trade, and finds it too costly to get further compensation by seizing other assets. Hence, our analysis is perhaps best suitable for security trading, where, in the event of default, the top priority for creditors is perhaps to get compensated quickly, rather than going through a lengthy bankruptcy procedure.[5] This lack of penalty upon default implies that investors need to post collateral to back up their promises.

Let us first consider the case where an investor can use any part of his portfolio as collateral. We

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[4]More formally, $\mathcal{H}$ is the probability space spanned by $\widetilde{V}$ and $\widetilde{U}$: $(\{V_d, V_u\} \times [-\Delta, \Delta], \mathcal{F}, \mathcal{P}_o, \mathcal{P}_p)$, where $\{V_d, V_u\} \times [-\Delta, \Delta]$ is the sample space, $\mathcal{F}$ is the sigma-algebra generated by $\{V_d, V_u\} \times [-\Delta, \Delta]$, and $\mathcal{P}_o$ and $\mathcal{P}_p$ are the probability measures for optimists and pessimists, respectively. Any security in this economy can be described as a claim to a cash flow, which can be described by a random variable in $\mathcal{H}$.

[5]This assumption can be broadly interpreted as limited enforcement. See Kehoe and Levine (1993) for an early contribution. This idea has lately been applied to asset pricing; see, e.g., Alvarez and Jermann (2000), Chien and Lustig (2010).

refer to this case as "portfolio margin." In this case, the collateral constraint is equivalent to the constraint that an investor's wealth has to be nonnegative. If investors introduce a complete set of Arrow securities, they can achieve the same equilibrium allocation and prices as in the traditional complete market equilibrium with a nonnegative wealth constraint. However, this case does not have sharp predictions on which market will be developed.

3.2 Individual Security Margin

The focus of our analysis is the friction in cross-netting. Specifically, we assume that investors have to post collateral for each security in their portfolios separately, which we refer to as "individual security margin." Suppose, for example, an investor holds a portfolio of assets whose returns offset each other. Under portfolio margin, the collateral requirement for the whole portfolio can be much lower than that under individual security margin.

In practice, however, cross-netting is far from perfect. For example, if one asset in the portfolio is exchange-traded, while the other is over-the-counter or traded on a different exchange, then the investor has to post collateral for each asset separately, even if these two positions largely offset each other. One famous example is that of Metallgesellschaft AG, a German conglomerate, which had a large short forward position in oil and an offsetting long position in oil futures in the early 1990s, but eventually ran into a liquidity crisis when the collateral requirement became excessive (see Culp and Miller (1995)). Moreover, it may be difficult or too costly for a dealer to precisely estimate the correlation among securities to determine the collateral for the whole portfolio. Or, a trader may prefer not to reveal his whole portfolio to his dealer by having multiple dealers, which is a common practice among hedge funds. Finally, different parts of the portfolio may be governed by different jurisdictions, and regulations may also put various constraints on collateralization.

Our individual security margin assumption captures these frictions by ruling out cross-netting. Under this assumption, when investors buy a risky asset, they can use the asset itself as collateral to borrow to finance the purchase. When an investor shorts a risky asset, he needs to put the

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proceedings as well as some of his own cash as collateral.[6] What is ruled out by the individual security margin assumption is the possibility of using one risky asset as collateral to long or short another risky asset. Our assumption reflects the practice in reality. For example, to purchase securities on margin is to use those securities themselves as collateral, and margin loans are generally not state contingent. The securities are placed in the margin account in "street name"—i.e., the broker-dealers are the legal owners and can liquidate those positions when investors fail to maintain certain margin requirements (see, e.g., Fortune (2000)). On the short side, as noted by Geczy, Musto, and Reed (2002), the collateral for equity loans is almost always cash, and the standard collateral for U.S. equities is 102% of the shares' value.

3.3 Equilibrium with Individual Security Margin

Due to the disagreement, it is natural to conjecture that investors will adopt a derivative contract, asset V, which is a claim to a cash flow $\widetilde{V}$ at $t = 1$. Before we demonstrate that asset V will indeed be adopted, we first construct the equilibrium, taking the market for asset V as given.

Suppose an investor purchases one unit of asset K ($K = A$ or V) and borrows L to finance this position. If the notional interest rate is $r(L, K)$, then, at time $t = 1$, the lender receives

$$X(L, K) \equiv \min \left(L(1 + r(L, K)), \widetilde{K} \right),$$

where $\widetilde{K}$ is the value of asset K at $t = 1$. That is, the lender receives $L(1 + r)$ when there is no default, and seizes the collateral asset K upon default (i.e., when $\widetilde{K} < L(1 + r)$). This levered long position has a payoff of

$$W^+(L, K) \equiv \widetilde{K} - X(L, K),$$

and requires $P_K - L$ capital from the investor at $t = 0$, where P_K is the price of asset K.

When taking a short position, the investor needs to use cash as collateral to back up his promise.

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[6]A long position in a claim to $-\widetilde{A}$ is the same as a short position in a claim to $\widetilde{A}$. However, this relabeling of long and short positions has no real impact. To see this, note that the derivative $-A$ has a negative price, i.e., an investor is "paid" when taking a long position. Using this derivative as collateral, an investor can only "borrow" a negative amount (i.e., the investor has to put up some of his own cash). In other words, a levered long position in $-A$ is the same as a short position in A.

Without loss of generality, we can assume that the short seller posts enough collateral and will not default. The reason is as follows. Suppose an investor promises a cash flow $\widetilde{K}$ at $t = 1$, and posts cash c as collateral; his real promise is $\min(c, \widetilde{K})$, rather than $\widetilde{K}$. That is, if we use the real promise to denote the contract, the short seller will not default. Hence, in order to credibly short one unit of asset K, a short seller needs to post $\max \widetilde{K}$ as collateral, where $\max \widetilde{K}$ is the maximum of $\widetilde{K}$ at time $t = 1$. This short position requires $\max \widetilde{K} - P_K$ capital from the short seller, and its payoff at time $t = 1$ is

$$W^-(K) \equiv \max \widetilde{K} - \widetilde{K}.$$

We use $\theta^+_{i,K}(L)$, for $i \in \{o, p\}$, $K \in \{A, V\}$, $\theta^+_{i,K}(L) \geq 0$ and $L \geq 0$, to denote the number of units of asset K that are held by investor i, who borrows L against each unit of asset K. Similarly, we use $\theta^*_{i,K}(L)$ to denote the number of units of asset K that are held by investors who borrow from investor i. That is, investor i lends $L\theta^*_{i,K}(L)$ to those investors and takes $\theta^*_{i,K}(L)$ units of asset K as collateral. We then define $M^+_{i,K}(x)$ such that $M^+_{i,K}(0) = 0$ and $dM^+_{i,K}(L) = \theta^+_{i,K}(L)$. That is, $M^+_{i,K}(x)$ is the total number of units of asset K that are held by investor i, who borrows less than or equal to x against each unit of asset K.[7] Similarly, we define $M^*_{i,K}(x)$ such that $M^*_{i,K}(0) = 0$ and $dM^*_{i,K}(L) = \theta^*_{i,K}(L)$. Finally, $\theta^-_{i,K}$ denotes the units of asset K that are shorted by investor i, and η_i denotes investor i's investment in the riskless technology, with $\theta^-_{i,K} \geq 0$ and $\eta_i \geq 0$. Hence, we can denote investor i's ($i = o, p$) wealth at time $t = 1$ as

$$W_i = \sum_{K=A,V} \left(\int_0^{P_K} W^+(L, K) dM^+_{i,K}(L) + W^-(K)\theta^-_{i,K} + \int_0^{P_K} X(L, K) dM^*_{i,K}(L) \right) + \eta_i. \tag{3}$$

Note that since one can always give up his collateral and default on his promise, no investor can borrow more than the collateral value. Hence, we do not need to consider the case of $L > P_K$.

Investor i's objective is to choose his portfolio $(M^+_{i,K}(L), M^*_{i,K}(L), \theta^-_{i,K}, \eta_i)$ for $K = A, V$ and

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[7]The relation between $\theta^+_{i,K}(\cdot)$ and $M^+_{i,K}(\cdot)$ is similar to that between a probability density function and its corresponding cumulative distribution function. The reason we need to define $M^+_{i,K}(x)$ is that, in the ensuing equilibrium, $\theta^+_{i,K}(L) = 0$ for all but a finite number of values of L. Hence, one cannot calculate the investor i's total holding in asset K by integrating $\theta^+_{i,K}(L)$ along L.

$L \in [0, P_K]$, to maximize his expected wealth at $t = 1$:

$$\max \mathbf{E}_i(W_i) \tag{4}$$

$$s.t. \sum_{K=A,V} \left(\int_0^{P_K} (P_K - L) dM_{i,K}^+(L) + \int_0^{P_K} L dM_{i,K}^*(L) + \theta_{i,K}^- \left(\max \widetilde{K} - P_K \right) \right) + \eta_i \leq e + \beta P_A. \tag{5}$$

where the left-hand side of (5) is the total capital an investor allocates to long positions, lending, short positions, and the riskless technology; the right-hand side is the investor's initial endowment.

Definition 1 *The equilibrium given the market for V is defined as the prices of assets A and V, (P_A, P_V), investors' holdings, $(M_{i,K}^+(L), M_{i,K}^*(L), \theta_{i,K}^-, \eta_i)$ for $i \in \{o, p\}$, $K \in \{A, V\}$ and $L \in [0, P_K]$, and the notional interest rates, $r(L, K)$, for all adopted loan contracts, such that for all investors, their holdings solve their optimization problem (4), and all markets clear:*

$$\sum_{i=o,p} \left(M_{i,A}^+(P_A) + \theta_{i,A}^- \right) = \beta; \tag{6}$$

$$\sum_{i=o,p} \left(M_{i,V}^+(P_V) + \theta_{i,K}^- \right) = 0; \tag{7}$$

and for $i \in \{o, p\}$, $j \neq i$, $K \in \{A, V\}$, and $L > \min \widetilde{K}$:

$$\theta_{j,K}^+(L) = \theta_{i,K}^*(L). \tag{8}$$

Equations (6) and (7) state that the aggregate demand is β units for asset A and zero for asset V. Equation (8) implies that borrowing is equal to lending for all loan markets with $L > \min \widetilde{K}$. Note that if $L \leq \min \widetilde{K}$, this borrowing is riskless and can be arranged through the riskless technology, rather than borrowing from some other investors in the economy.[8] To best illustrate our main results, we will focus on the case $\underline{\alpha} \leq \alpha_p \leq \overline{\alpha}$, where

$$\underline{\alpha} \equiv \frac{\gamma - \gamma h_o}{\gamma + \beta h_o}, \text{with } \gamma = \frac{h_o \left[e + \beta \left(V_d - \Delta \right) \right]}{h_o \left(V_u - V_d \right) + \Delta},$$

and $\overline{\alpha}$ is given by (22) in the Appendix. The results from other cases are similar, but require messier algebra.

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[8]One interpretation is the following. The cash collateral in the economy is kept at a custodian bank, which can invest the cash only in riskless investments. So, if an investor has sufficient collateral to guarantee no default, he can borrow from this custodian bank at the riskless interest rate.

Proposition 1 *In the case $\underline{\alpha} \leq \alpha_p < \overline{\alpha}$, the equilibrium is characterized as follows:*

1. *The prices of assets A and V are given by*

$$P_A = \frac{e\alpha_o + (\gamma + \beta)(V_d - \Delta)}{\gamma + \beta\alpha_p}, \tag{9}$$

$$P_V = \frac{\gamma\alpha_o}{\gamma + \beta\alpha_p}V_u + \frac{(\gamma + \beta)\alpha_p}{\gamma + \beta\alpha_p}V_d. \tag{10}$$

2. *A fraction $\beta/(\gamma + \beta)$ of the optimists hold a levered position in asset A. Each investor holds $(\gamma + \beta)/\alpha_o$ units and borrows $V_d - \Delta$ against each unit of asset A, with an interest rate of 0.*

3. *A fraction $\gamma/(\gamma + \beta)$ of the optimists take a levered position in asset V. Each of them holds $\frac{e+\beta P_A}{P_V - V_d}$ units and borrows V_d against each unit of asset V, with an interest rate of 0.*

4. *Each pessimist shorts $\frac{e+\beta P_A}{V_u - P_V}$ units of asset V. For each unit of the short position, the investor posts V_u cash as collateral.*

This proposition highlights the collateral motivation in financial innovation. One unit of asset A and one unit of asset V give investors the same exposure to $\widetilde{V}$. However, asset V allows the buyer to take a higher leverage: As shown in the proposition, an investor can borrow only $V_d - \Delta$ against each unit of A, but can borrow V_d against each unit of V. What is the cause of this difference? Note that the cash flow from the underlying asset has two portions, $\widetilde{V}$ and $\widetilde{U}$, but investors are only interested in $\widetilde{V}$. The "unwanted" portion, $\widetilde{U}$, increases the collateral requirement for a levered position in A. That is, the investor has to "waste" his collateral to cover the risk he is not interested in taking. This is unappealing even if the investor is risk neutral. If assets A and V had the same price, the buyer would strictly prefer V. Indeed, from equations (9) and (10), one would find that P_A is lower than P_V. This price discount reflects the shadow value of collateral and compensates investors who hold asset A. In equilibrium, a fraction $\beta/(\gamma+\beta)$ of optimists hold a levered position in asset A, the rest of the optimists hold a levered position in the derivative V, and they are indifferent about these two positions.[9]

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[9] Investors are risk neutral. Therefore, if they are indifferent about the two strategies, they are also indifferent about any combination of the two strategies. Hence, we can also interpret the result as "a fraction $\beta/(\gamma + \beta)$ of optimists' wealth is invested in the levered position in A and the rest of their wealth in the levered position in V."

The collateral requirements for both the underlying asset and the derivative are endogenously determined in equilibrium. If an optimist wants to take a levered position in A, he can borrow at the riskless interest rate, 0, if he posts enough collateral to guarantee no default. Alternatively, he can reach out to other investors to enter a loan contract, if he and the lenders can agree on the collateral and interest rate. For example, if an optimist borrows more than $V_d - \Delta$ against each unit of asset A, he has to offer a higher interest rate to compensate his lender for the default risk. If a pessimist agrees to lend, this choice has to be no worse than his outside option, which is taking a short position in V. In the case $\underline{\alpha} \leq \alpha_p < \overline{\alpha}$, optimists cannot offer an interest rate that is high enough to attract pessimists to lend to them.[10] Therefore, in equilibrium, optimists borrow $V_d - \Delta$ against each unit of asset A, and the interest rate is 0. For the same reason, optimists borrow V_d against each unit of asset V, and the interest rate is 0.

Finally, pessimists short V but not A. The reason is that due to the unwanted risk $\widetilde{U}$, in order to obtain the same exposure to $\widetilde{V}$, shorting A requires more collateral. In addition, as noted earlier, P_A is lower than P_V. This makes shorting A even less appealing.

In summary, the above discussion suggests that trading asset A needs more collateral due to the "unwanted" risk from $\widetilde{U}$. The derivative contract is appealing because it "carves" out the unwanted risk. This intuition suggests that the derivative contract that completely carves out the unwanted cash flow should be the "most appealing" financial innovation in the economy, as we formally analyze next.

3.4 Optimal Financial Innovation

Definition 2 *A derivative K (a claim to a cash flow $\widetilde{K}$ in $\mathcal{H}$ at $t = 1$) is optimal if, in the presence of K, one introduced any other derivative contract K' (a claim to a cash flow $\widetilde{K'}$ in $\mathcal{H}$ at $t = 1$), the market for K' would not generate any trading, unless $\widetilde{K'}$ is perfectly correlated with $\widetilde{K}$.*

Proposition 2 *The derivative contract V is an optimal financial innovation.*

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[10]As discussed in the Appendix, for other parameters, investors may agree on loan contracts with default risk.

Due to the disagreement, optimists prefer to transfer their wealth at $t = 1$ to the up state ($\widetilde{V} = V_u$) and pessimists to the down state ($\widetilde{V} = V_d$). Derivative V is the most efficient instrument since it allows investors to transfer all their wealth to the states they prefer. For example, as shown in Proposition 1, the buyer of asset V borrows V_d against each unit. Hence, he makes a large profit at the up state but loses all his wealth at the down state, which is efficient from an optimist's perspective. Alternative assets cannot achieve this goal. For example, an investor can borrow only $V_d - \Delta$ against each unit of A. Therefore, he cannot completely transfer his wealth to the up state, as his wealth at the down state is always positive unless the realization of $\widetilde{A}$ happens to be $V_d - \Delta$. This makes A unappealing for an optimist.

3.5   Asset Prices

As discussed earlier, holding A is inefficient due to its higher collateral requirement. In equilibrium, therefore, to induce an investor to hold it, there has to be a price discount relative to V. Note that asset A can be decomposed into assets V and U, where asset U is a claim to a cash flow $\widetilde{U}$ at $t = 1$. Using P_U to denote the price of asset U, the price difference between asset A and its replicating portfolio is $P_V + P_U - P_A$, which can be decomposed into two components: $S \equiv P_V - P_A$ and P_U. The first component reflects the shadow value of collateral, while the second component is determined by how much investors value asset U.[11] The following proposition characterizes the behavior of S.

Proposition 3 *The price spread S is positive and has the following properties:*

1. *S increases when there is less cash in the economy: $\frac{\partial S}{\partial e} < 0$.*

2. *S increases when asset A has more unwanted risk: $\frac{\partial S}{\partial \Delta} > 0$.*

3. *The impact in item 1 is stronger when there is more unwanted risk: $\frac{\partial^2 S}{\partial e \partial \Delta} < 0$.*

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[11]In the empirical interpretations later, asset U corresponds to a Treasury bond. It is perhaps natural to expect that the price of asset U is determined by investors outside our model. Note also that if P_U is close to 0, both optimists and pessimists in our model choose not to trade asset U even if they have access to this market, and the equilibrium prices of A and V are the same as those in Proposition 1.

4. *Suppose that an outside investor has to sell β^* units of asset A to the investors in this economy. The spread increases: $\frac{\partial S}{\partial \beta^*} > 0$, and this impact is stronger when there is more unwanted risk: $\frac{\partial^2 S}{\partial \beta^* \partial \Delta} > 0$.*

5. *S increases with the disagreement among investors: $\frac{\partial S}{\partial h_o} > 0$.*

Result 1 shows that this spread increases when investors face tighter funding liquidity. This is because saving collateral is more valuable when investors have less cash but need leverage. Similarly, Result 2 says that the spread is larger if $\widetilde{U}$ is more volatile (i.e., Δ is larger). The larger the risk in $\widetilde{U}$, the more collateral can be saved by trading V, leading to a larger price spread. Result 3 shows that when the funding liquidity in the economy tightens (i.e., e decreases), the spread increases more for assets with more volatile unwanted cash flow (i.e., larger Δ).

These implications are consistent with the empirical evidence on the corporate bond–CDS basis, the difference between the CDS spread and the corresponding corporate bond yield spread. As noted in Mitchell and Pulvino (2010), CDS spreads tend to be lower than the corresponding corporate bond yield spreads, although both are measures of the underlying firm's credit risk, and the no-arbitrage relation implies that the difference between the two should be near zero. A corporate bond, like asset A in our model, can be decomposed into a short position in a CDS contract on the bond issuer (asset V) and a Treasury bond (asset U). The corporate bond-CDS basis implies that the corporate bond price is lower than its replicating portfolio. An important determinant of the corporate bond–CDS basis is the price spread S. Consistent with the proposition, their evidence shows that the basis increases during the recent financial crisis (Result 1), and increases more for junk bonds (Result 3). Another example is the TIPS–inflation swap basis. Fleckenstein, Longstaff, and Lustig (2010) find that the price of TIPS is consistently lower than the price of its replicating portfolio, which consists of inflation swaps and nominal Treasury bonds. Consistent with Result 1, this basis also increased during the recent financial crisis.

Results 1–3 are similar to those in Garleanu and Pedersen (2011), where the financial assets and collateral requirements are exogenous. In contrast, our model endogenizes both financial innovation

and the collateral requirements, and explains why differential collateral requirements arise in the first place. Our analysis shows that it is not a coincidence that derivatives are more collateral efficient than the underlying assets—this is precisely the motivation for designing those derivatives.

Our model also has several new predictions. For example, if a large investor (e.g., a failing hedge fund) has to liquidate his positions in asset A at $t = 0$, what is the impact of this supply shock on equilibrium prices? Clearly, the prices of both A and V will drop. Result 4 shows that the price of A drops more—i.e., the supply shock increases the spread. This is because it requires more capital to absorb A than to absorb V. Therefore, the price of A is more sensitive to supply shocks. Similarly, the impact of supply shocks is stronger on assets with a larger unwanted risk (larger Δ). Finally, Result 5 shows that the spread increases with the disagreement among investors. Holding everything else constant, an increase in h_o (i.e., optimists become even more optimistic) increases the disagreement among investors. This increases investors' desire to trade, leading to a higher shadow value of collateral, and hence a higher the price spread.

4　Financial Intermediation

In the above analysis, investors can directly design securities. In practice, however, security design is mostly controlled by financial intermediaries (e.g., investment banks, broker-dealers, exchanges), and investors take securities as given. This section introduces intermediaries into the above economy, and focuses on two aspects. The first one, analyzed in Section 4.1, is that financial intermediation arises as a response to the frictions in cross-netting. Institutions that are equipped with more efficient cross-netting technologies can provide valuable services to investors, leading to asset-backed securities and tranching. Second, intermediaries design securities and also charge a fee when investors trade them. Section 4.2 analyzes if this profit motive distorts the security design.

4.1　Asset-Backed Securities and Tranching

The key friction in our model is the inefficiency in cross-netting. This gives rise to a role for financial intermediation. Institutions with more efficient cross-netting technologies can create value.

For example, as shown in Propositions 1 and 3, due to the collateral friction, asset A has a price discount in equilibrium. Hence, a financial intermediary can buy A and use it as collateral to issue asset-backed securities that investors find more appealing. For instance, the intermediary can issue two tranches T_u and T_d, which are claims to cash flows $\widetilde{T}_u$ and $\widetilde{T}_d$, respectively, where

$$\widetilde{T}_u = \begin{cases} V_u + \widetilde{U} & \text{if } \widetilde{V} = V_u, \\ 0 & \text{if } \widetilde{V} = V_d, \end{cases} \tag{11}$$

$$\widetilde{T}_d = \begin{cases} 0 & \text{if } \widetilde{V} = V_u, \\ V_d + \widetilde{U} & \text{if } \widetilde{V} = V_d. \end{cases} \tag{12}$$

Note that issuing asset-backed securities requires cross-netting and is not feasible for investors. Intermediaries' advantage is their capacity to set up special purpose vehicles (SPVs) that collect the cash flows from asset A, then divide and distribute them to the holders of the two tranches. The essence is that these activities cost less for intermediaries than for investors. Let us first analyze the prices of the two tranches when an intermediary produces a small amount of T_u and T_d, and so has no impact on the prices in the equilibrium in Proposition 1.

Proposition 4 *Suppose an intermediary acquires an infinitesimal amount of asset A from the economy analyzed in Proposition 1, and sells the two tranches, T_u and T_d to investors. The prices of T_u and T_d are given by*

$$P_u = \frac{\gamma \alpha_o}{\gamma + \beta \alpha_p} V_u, \tag{13}$$

$$P_d = \frac{(\gamma + \beta)\alpha_p}{\gamma + \beta \alpha_p} V_d, \tag{14}$$

and the sum of the prices of the two tranches is $P_u + P_d = P_V$.

In this case, optimists are indifferent between holding T_u and taking a levered position in V, while pessimists are indifferent between holding T_d and shorting V. The sum of the prices of the two tranches is exactly the price of V. Hence, the intermediary pays P_A to acquire one unit of A and receives P_V from selling the two tranches. The difference, $P_V - P_A$, is the intermediary's profit, which is also the value created by the intermediary.

The profit will draw more and more intermediaries to enter the market. With competitive intermediaries, as long as the profit exists, intermediaries have the incentive to acquire more of asset A to tranch, and this demand affects the prices of all assets in the economy. In the following, we consider the case $\alpha_p \in [\underline{\alpha}^*, \bar{\alpha}^*]$, where

$$
\begin{aligned}
\bar{\alpha}^* &\equiv \frac{(1 - h_o)(e + \beta V_d)}{e + \beta(h_o V_u + (1 - h_o) V_d)}, \\
\underline{\alpha}^* &\equiv \frac{(1 - h_p)(e + \beta V_d)}{e + \beta(h_p V_u + (1 - h_p) V_d)},
\end{aligned}
$$

since other cases are uninteresting and completely dominated by one group of investors. For brevity, the following proposition reports only asset prices, and leaves investors' holdings to the Appendix.

Proposition 5 *With competitive intermediaries, in the case $\alpha_p \in [\underline{\alpha}^*, \bar{\alpha}^*]$, intermediaries tranch all β units of asset A into T_u and T_d, and equilibrium prices are given by*

$$
\begin{aligned}
P_u &= \frac{\alpha_o(e + \beta V_d)}{\alpha_o(e + \beta V_d) + \alpha_p(e + \beta V_u)} V_u, \\
P_d &= \frac{\alpha_p(e + \beta V_u)}{\alpha_o(e + \beta V_d) + \alpha_p(e + \beta V_u)} V_d, \\
P_A &= P_V = P_u + P_d.
\end{aligned}
$$

Optimists are indifferent between holding T_u and taking a levered long position in V, and pessimists are indifferent between holding T_d and shorting V.

As shown in the above proposition, intermediaries sell each tranch to the investors who value it the most: T_u to optimists and T_d to pessimists. Intermediaries' demand for asset A pushes up its equilibrium price. With competitive financial intermediaries, they push up P_A to P_V, and hence make zero profit in equilibrium. This result is, of course, due to the assumption that intermediaries face no cost when issuing asset-backed securities. It is straightforward to see that in the presence of a cost for tranching asset A, there will be a spread between P_A and P_V in equilibrium, which reflects this cost.

4.1.1 Timing of Financial Innovations

Fostel and Geanakoplos (2012) noted that while mortgage securitization and tranching grew rapidly throughout the 1990s and early 2000s, the CDS for mortgages became standardized only in 2005, shortly before the collapse of the housing market. They argue that the timing (tranching before CDS) might have exacerbated the housing boom and crash.

Our previous analysis suggests that this timing of innovations might be a natural choice by financial intermediaries. In our model, tranching corresponds to issuing T_u and T_d, and the CDS for mortgages corresponds to the derivative V. In the "pre-innovation era," investors can only trade asset A, and the markets for V, T_u, T_d have not been developed. Suppose a financial institution becomes the first to get the ideas of the two innovations: tranching asset A and introducing security V. Which one will the institution adopt first? Note that introducing V is equivalent to tranching cash: turning one dollar into two Arrow securities. One pays a dollar if $\widetilde{V} = V_u$ and zero otherwise, while the other pays a dollar if $\widetilde{V} = V_d$ and zero otherwise. The analysis in Proposition 1 implies that the total price of these two Arrow securities is one dollar. Hence, the institution has zero profit from tranching cash. In contrast, as illustrated in Proposition 4 (except that there is no asset V), if the institution can acquire asset A at the current prevailing price, it can make a profit from tranching it into T_u and T_d. The intuition is that tranching A requires cross-netting, and only financial intermediaries have this capacity. Hence, the first mover can earn a profit. However, the institution cannot make a profit from tranching cash because investors can effectively supply those two Arrow securities by taking short positions in them. Therefore, intermediaries prefer to tranch asset A first. Interestingly, anecdotes suggest that part of the reason that intermediaries started introducing CDS for mortgages in 2005 was that they "ran out of mortgages" to tranch.[12]

4.2 Maximizing Commission Fees

Another important aspect of financial intermediation is that intermediaries (e.g., broker-dealers, exchanges) design securities and also make profits when investors trade them. This section analyzes

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[12]Michael Lewis, 2010, *The Big Short: Inside The Doomsday Machine*, W.W. Norton and Company.

how this profit motive distorts the security design.

Following Duffie and Jackson (1989), we assume that the intermediary can charge a fee for each contract investors trade, and its objective is to maximize the total fee by designing the contracts and setting the fee level. Taking the derivatives designed by the financial intermediary as given, investors choose their portfolios at $t = 0$ to maximize their expected wealth at $t = 1$, and face the individual security margin constraint described in Section 3.2. The equilibrium in this economy is obtained when all investors and the financial intermediary optimize and all markets clear. To shut down the tranching channel analyzed previously, we focus on the case of $\beta = 0$. The following proposition is for the case where the intermediary has monopoly power.

Proposition 6 *In the case of $\beta = 0$, V is an optimal contract for the monopolistic intermediary.*

This proposition shows that in equilibrium, the profit-optimizing financial intermediary chooses the same derivative as in the model where investors can design the contract themselves. As shown earlier, given the collateral friction in Section 3.2, investors find asset V most appealing. Hence, the financial intermediary can maximize the fees from investors if it introduces asset V. Alternative derivative contracts are less appealing to investors, and hence the intermediary will not be able to charge as much fees. In other words, the profit motive of the monopolistic intermediary does not affect the design of the derivative. However, the intermediary extracts all the surplus from the innovation.

This result is in contrast to that in Duffie and Jackson (1989), where the intermediary may distort the security design to maximize his profit. The key difference is that in our model, the fee charged by the intermediary is endogenous: if the contract is more appealing to investors, the intermediary can charge a higher fee. In Duffie and Jackson (1989), however, the fee is set exogenously, so that the intermediary does not have the incentive to design the security that is most appealing to investors, but focuses on maximizing the trading volume instead.

In the above discussion, the financial intermediary faces no competition. It is easy to see that competition will drive down the fee. In the extreme case in which the financial intermediary faces

no cost in designing securities, competition will drive the fee to zero, and the equilibrium will converge to the one in Section 3. That is, competition among intermediaries does not affect the design of the derivative either. It just reallocates the surplus from intermediaries to investors.

5 Collateral Motivation vs. Completing Markets

The main insight from our analysis is carving out unwanted cash flow to isolate the variable with disagreement. This is distinct from the standard intuition of completing markets. The following example illustrates that, in an economy with N states, investors may choose to introduce more than N securities and, yet, markets are still incomplete. The securities that investors choose to introduce may appear redundant, and are simply linear combinations of several other securities.

There are N possible states, $S = \{s_1, s_2, ..., s_N\}$, and the true state will be realized at $t = 1$. All investors are risk neutral and are endowed with \$1 at $t = 0$. Their objective is to maximize their expected wealth at $t = 1$. They can be classified into M groups. For each group, there are two (types of) investors, who disagree on the probabilities of two states but agree on the rest of the $N-2$ states. Specifically, for $1 \leq i < j \leq N$, group (i, j) investors believe that $\Pr(s_k) = \frac{1}{N}$, for $k \neq i$ and $k \neq j$. However, one investor in group (i, j) believes that $\Pr(s_i) = \frac{1}{N} + x$ and $\Pr(s_j) = \frac{1}{N} - x$, with $0 < x < 1/N$, while the other believes that $\Pr(s_j) = \frac{1}{N} + x$ and $\Pr(s_i) = \frac{1}{N} - x$.

From the analysis in Section 3, it is easy to see that in the presence of the cross-netting friction, the optimal security for the investors in group (i, j), denoted as D_{ij}, is a claim to the following cash flow at $t=1$:

$$\begin{cases} 1 & \text{in state } s_i, \\ -1 & \text{in state } s_j, \\ 0 & \text{otherwise.} \end{cases} \tag{15}$$

By taking positions in D_{ij}, investors can move all their wealth to the states that they believe are most likely, and their allocations are Pareto optimal. Since each group of investors designs a security for its specific speculation needs, there are M securities in equilibrium. Note that M can be as high as $\binom{N}{2} = N(N-1)/2$. If there are some states that all investors agree on, there will not be securities spanning those states. Therefore, it is possible that investors may choose to introduce

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more than N securities, and markets are still incomplete. Moreover, the securities that investors introduce may appear redundant: For example, groups (1,2), (2,3), and (1,3) choose to introduce securities D_{12}, D_{23}, and D_{13}, although D_{13} is simply a linear combination of D_{12} and D_{23}. In equilibrium, all three securities are not only actively traded, but also irreplaceable by combinations of other securities due to the friction in cross-netting.

The above example offers one explanation for the prevalence of securities with similar, sometimes apparently redundant, payoffs. For example, there are more than 800 one-month options on the S&P 500 index on the Chicago Board of Exchange.[13] There are also ten other maturities and hundreds of contracts for each maturity. While the traditional view implies that one may introduce options with various strike prices to complete markets, it does not explain the purpose of many options whose payoffs are linear combinations of a few other options. Under our collateral view, however, this phenomenon is natural: those options with various strike prices and maturities enable investors to speculate, or hedge, on certain states most efficiently. Although one can replicate an option by a number of other options, due to the inefficiency in cross-netting, one may have to post substantially more collateral for the replicating portfolio.

6 General Discussions

This collateral view of financial innovation highlights a common theme behind a variety of innovations with strikingly different appearances, such as the invention of new securities, legal entities, legal practice, as well as policy and rule changes.

As noted earlier, by carving out unwanted cash flows, many derivatives, such as swaps, allow investors to get large exposures with very little collateral. This intuition also applies to the evolution of a legal practice, the so-called superseniority of derivatives. Although derivatives are not supersenior in a strict statutory sense, it has been a common practice in the U.S.: When an institution goes bankrupt, its derivative counterparties can simply seize the collateral posted in the transactions

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[13]See, www.cboe.com.

instead of going through a lengthy and costly bankruptcy procedure.[14] This exceptional treatment accorded derivatives in bankruptcy is recent and has been evolving over time. In the context of our analysis, this practice can also be viewed as carving out unwanted cash flows: Suppose an investor enters an interest rate swap to hedge or speculate on interest rate risk. Without superseniority, even if his counterparty posts a large amount of collateral, the investor is still not well protected since he would have to go through the bankruptcy procedure when his counterparty defaults. With superseniority, however, the investor can immediately seize the collateral upon default, and so can be better protected even by a smaller amount of collateral. In other words, superseniority separates the asset of the investor's counterparty into two parts, the collateral posted to the swap transaction and other assets. From the investor's perspective, the latter part is unwanted. The collateral efficiency is achieved when those unwanted cash flows are carved out of the swap transaction by superseniority.[15]

Moreover, financial innovations may take the form of legal entities, such as SPVs in securitization. In our analysis in Section 4.1, SPVs are part of the cross-netting technology that allows financial intermediaries to overcome the collateral friction. Moreover, in the context of our analysis, we can view creating an SPV as, again, carving out unwanted cash flows. An SPV is an independent legal entity. Hence, when asset-backed securities are issued against assets in an SPV, the investors of the asset-backed securities don't have to consider the credit risk of the SPV sponsor. That is, by creating an SPV, it carves out the unwanted credit risk of the SPV sponsor.[16]

Finally, the collateral friction in our model arises from the limitations in cross-netting. Hence, one can view the continuing efforts by regulators and market participants in improving the margin procedure, from the ISDA Master Agreement to numerous rules and regulations by exchanges and

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[14]In the Lehman bankruptcy case, for example, 80% of Lehman's derivative counterparties terminated their contracts within five weeks after the bankruptcy filing (Summe (2011)). In the bankruptcy procedure, however, the final settlement plan was approved more than three years later, in which the senior bondholders get only 21.1 cents on the dollar (*Financial Times*, December 6, 2011, Court Approves Lehman Pay-out Plan).

[15]Our focus here is the collateral efficiency for derivative traders. We do not attempt to evaluate the overall impact of this practice. See Bolton and Oehmke (2012) for an analysis of the impact of superseniority on corporate policies. Duffie and Skeel (2012) offer broader discussions on the pros and cons of this practice.

[16]This is related to the theory of Gorton and Souleles (2006), which emphasizes the benefit of making SPVs bankruptcy remote to avoid bankruptcy cost.

broker-dealers, as a form of collateral-motivated financial innovation. Their goal is simply to satisfy the demand from market participants to alleviate their collateral constraints.

7   Conclusion

This paper proposes a collateral view of financial innovation: Many successful innovations, despite their strikingly different appearances, share the common motive of reducing collateral requirements to facilitate trading. We illustrate this insight in an equilibrium model in which both the financial innovation and collateral requirements are endogenous. When there is a collateral friction in cross-netting, the optimal security is the one that isolates the variable with disagreement. It is optimal in the sense that in the presence of this optimal security, alternative derivatives cannot generate any trading. This collateral friction leads to a basis, a spread between the prices of an asset and its replicating portfolio, which reflects the shadow value of collateral, and increases when there is a supply shock or when there is a stronger trading need. As a response to this collateral friction, financial intermediation arises, leading to asset-backed securities and tranching. This view of financial innovation is distinct from the traditional view of completing markets: We demonstrate that in an economy with N states, investors may prefer to introduce more than N securities, and yet still don't complete the markets. The securities they choose to introduce may appear redundant, and are simple linear combinations of a few other existing securities.

Appendix

Proof of Proposition 1

We first conjecture that the equilibrium is as follows: $x_o \in [0, \alpha_o)$ optimists invest all their wealth in a levered long position in asset V and the remaining, $\alpha_o - x_o$, invest all their wealth in a levered long position in asset A, and all pessimists short asset V. Moreover, using each unit of asset A as collateral, an optimist borrows $V_d - \Delta$, and the interest rate is 0. Using each contract V as collateral, an optimist borrows V_d, and the interest rate is 0. We then derive the market-clearing prices under this conjecture before verifying that it is indeed sustained in equilibrium.

To hold one unit of asset V, an investor needs $P_V - V_d$ capital since he can use the asset as collateral to borrow V_d. So the aggregate demand from x_o optimists is $x_o \frac{e + \beta P_A}{P_V - V_d}$. Similarly, pessimists' aggregate short position in asset V is $\alpha_p \frac{e + \beta P_A}{V_u - P_V}$. So, the market-clearing condition in the market for asset V is:

$$x_o \frac{e + \beta P_A}{P_V - V_d} = \alpha_p \frac{e + \beta P_A}{V_u - P_V}. \tag{16}$$

Similarly, the market-clearing condition in the market for asset A is:

$$(\alpha_o - x_o) \frac{e + \beta P_A}{P_A - (V_d - \Delta)} = \beta. \tag{17}$$

The expected payoff for an optimist to borrow V_d to hold one unit of V is $\mathbf{E}_o[\widetilde{V}] - V_d$. So the expected return of this levered position is $\frac{\mathbf{E}_o[\widetilde{V}] - V_d}{P_V - V_d}$. Similarly, the expected return of the levered position in asset A is $\frac{\mathbf{E}_o[\widetilde{A}] - (V_d - \Delta)}{P_A - (V_d - \Delta)}$. Optimists are indifferent about these two strategies:

$$\frac{\mathbf{E}_o[\widetilde{V}] - V_d}{P_V - V_d} = \frac{\mathbf{E}_o[\widetilde{A}] - (V_d - \Delta)}{P_A - (V_d - \Delta)}. \tag{18}$$

Similarly, pessimists' expected return from shoring V is

$$\frac{V_u - \mathbf{E}_p[\widetilde{V}]}{V_u - P_V}. \tag{19}$$

From (16)–(18), we obtain (9), (10), and $x_o = \beta/(\beta + \gamma)$.

To verify that the conjecture is an equilibrium, we need to show the following: (a) No investor prefers to invest in the riskless technology. (b) Pessimists prefer to short V rather than shorting

A. (c) Optimists prefer to borrow $V_d - \Delta$ against each unit of asset A as collateral. (d) Optimists prefer to borrow V_d against each unit of asset V as collateral.

Equation (10) implies that $\mathbf{E}_o[\widetilde{V}] < P_V < \mathbf{E}_o[\widetilde{V}]$. Therefore, trading V strictly dominates the investment in the riskless technology, implying (a). It is also straightforward to verify (b) by directly calculating the expected utility from shorting V and shorting A.

Using each unit of asset A as collateral, optimists will not borrow less than $Y_d - \Delta$. This is because they can borrow more at a zero-interest rate and their expected return for the investment in asset A is positive. Hence, to prove (c), we just need to verify that optimists will not choose to borrow more than $Y_d - \Delta$. Note that if they borrow more than $Y_d - \Delta$, they have to compensate the lender by offering a higher interest rate. Equations (18) and (19) imply that if optimists and pessimists agree on the loan, the following two inequalities have to hold

$$\frac{\mathbf{E}_p\left[\min\left\{\widetilde{A}, L(1+r)\right\}\right]}{L} \geq \frac{V_u - \mathbf{E}_p[\widetilde{V}]}{V_u - P_V}, \tag{20}$$

$$\frac{\mathbf{E}_o\left[\max\left\{\widetilde{A} - L(1+r), 0\right\}\right]}{P_A - L} \geq \frac{\mathbf{E}_o[\widetilde{V}] - V_d}{P_V - V_d}, \tag{21}$$

where r is the notional interest rate in the loan contract. The left-hand side of (20) is pessimists' expected return from lending, and the right-hand side is their expected return from shorting asset V. Similarly, the left-hand side of (21) is optimists' expected return from the levered position in A, and the right-hand side is their expected return from the levered position in asset V.

By changing the inequalities in (20) and (21) into equalities, we obtain an equation system of L and r. We show in the online Appendix that there exists a unique value $\hat{\alpha}$, $0 < \hat{\alpha} < 1$, such that if $\alpha_p = \hat{\alpha}$ there is a unique solution for this equation system. We define

$$\overline{\alpha} \equiv \hat{\alpha}. \tag{22}$$

Moreover, the online Appendix also shows that if $\underline{\alpha} \leq \alpha_p < \overline{\alpha}$, inequalities (20) and (21) cannot hold simultaneously for any values of L and r—i.e., optimists and pessimists cannot agree on any loan contract. This verifies (c). The proof for (d) is similar. The online Appendix also constructs

the equilibrium for the case of $\alpha_p > \overline{\alpha}$, where optimists can borrow from pessimists and the interest rate is positive to compensate for the credit risk.

Proof of Proposition 2

We offer here an intuitive proof, and leave the algebra to the online Appendix. Asset V allows investors to transfer all their wealth at $t = 1$ to the states they prefer, so it weakly dominates all other instruments. Moreover, if the derivative K is not perfectly correlated with V, traders in this market cannot all transfer wealth to the states they prefer. Suppose, in equilibrium, asset K generates some trading. Then, it is possible to Pareto-improve the welfare of those traders if they simply move to the market for asset V, a contradiction.

Proof of Proposition 3

Differentiating S leads to all results except those in 4. To prove 4, we derive the equilibrium prices when the total supply of asset A is $\beta + \beta^*$. Results in 4 can then be obtained by differentiating S in this new equilibrium.

Proof of Proposition 4

Similar to the argument in the proof of Proposition 1, it is optimal for investors to not take leverage when they buy T_u and T_d. Hence, optimists' and pessimists' indifference conditions are

$$
\frac{\mathbf{E}_o[\widetilde{V}] - V_d}{P_V - V_d} = \frac{\mathbf{E}_o[\widetilde{T}_u]}{P_u},
$$
$$
\frac{V_u - \mathbf{E}_p[\widetilde{V}]}{V_u - P_V} = \frac{\mathbf{E}_p[\widetilde{T}_d]}{P_d}.
$$

The above two equations lead to (13) and (14). Hence, $P_u + P_d = P_V$.

Proof of Proposition 5

Suppose that a fraction $x_o \in [0, \alpha_o]$ of optimists hold T_u, and the rest of them take a levered position in V. A fraction $x_p \in [0, \alpha_p]$ of pessimists hold T_d, and the rest of them take a levered position in

V. The intermediaries tranch all asset A. The market-clearing conditions for T_u and T_d are

$$x_o \frac{e + \beta P_A}{P_u} = \beta, \tag{23}$$

$$x_p \frac{e + \beta P_A}{P_d} = \beta. \tag{24}$$

Optimists are indifferent between holding T_u and a levered position in V:

$$\frac{h_o V_u}{P_u} = \frac{h_o \left(1 - x_o - x_p\right)}{\alpha_o - x_o}. \tag{25}$$

Pessimists are indifferent between holding T_d and shorting V:

$$\frac{\left(1 - h_p\right) V_d}{P_d} = \frac{\left(1 - h_p\right)\left(1 - x_o - x_p\right)}{\alpha_p - x_p}. \tag{26}$$

The market-clearing condition for V is given by

$$\left(\alpha_o - x_o\right) \frac{e + \beta P_A}{P_V - V_d} = \left(\alpha_p - x_p\right) \frac{e + \beta P_A}{V_u - P_V}. \tag{27}$$

The intermediary's zero-profit condition requires that

$$P_u + P_d = P_A. \tag{28}$$

We have six unknowns, x_o, x_p, P_u, P_d, P_A, and P_V, and six equations $(23) - (28)$. Solving this equation system, we obtain the four prices, P_u, P_d, P_A, and P_V, in the proposition and

$$x_o = \alpha_o \frac{\beta V_u}{e + \beta V_u},$$

$$x_p = \alpha_p \frac{\beta V_d}{e + \beta V_d}.$$

It is easy to verify that in the region $[\overline{\alpha}^*, \underline{\alpha}^*]$, all investors' expected returns are nonnegative. Hence, investors' holdings are as follows. A fraction $1 - x_o$ optimists take a levered position in V. Each of them holds $\left(1 + \frac{\alpha_p}{\alpha_o} \frac{e + \beta V_u}{e + \beta V_d}\right) \frac{e + \beta P_A}{V_u - V_d}$ units of V, and borrows V_d against each unit, with an interest rate of 0. A fraction $1 - x_p$ pessimists short asset V. Each of them shorts $\left(1 + \frac{\alpha_o}{\alpha_p} \frac{e + \beta V_d}{e + \beta V_u}\right) \frac{e + \beta P_A}{V_u - V_d}$ units and posts V_u cash as collateral for each unit.

Proof of Proposition 6

We use $\widetilde{W}_i$, for $i = o, p$, to denote investor i's wealth at $t = 1$, and C to denote the total fee the intermediary charges all investors. The intermediary's objective is to maximize C, subject to

$$\mathbf{E}_o[\widetilde{W}_o] = e\alpha_o, \tag{29}$$

$$\mathbf{E}_p[\widetilde{W}_p] = e\alpha_p, \tag{30}$$

$$\widetilde{W}_o + \widetilde{W}_p = e - C. \tag{31}$$

The first two equations are investors' participation constraints. They are binding because the monopolistic intermediary can always increases the fee until it extracts all the surplus from trade. The third equation is an accounting identity. From (29)–(31), after some algebra, we obtain

$$(h_o - h_p)\, e - (h_o - h_p)\left(W_p^u + W_o^d\right) = (1 + h_o - h_p)\, C, \tag{32}$$

where W_i^u and W_i^d denote investor i's expected wealth in the up state and down state, respectively. Note that conditional on the up state, or down state, investors share the same probabilities. Equation (32) implies that maximizing C is equivalent to minimizing $W_p^u + W_o^d$. Since $\widetilde{W}_o$ and $\widetilde{W}_p$ are nonnegative, the optimum is achieved at $W_p^u = W_o^d = 0$. This implies that optimists get all the wealth, $e - C$, at the up state and pessimists get all the wealth, $e - C$, at the down state. This can only be achieved by asset V.

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