Security Design: A Review

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Abstract

Security design, which broadly speaking deals with the issue of designing optimal contractual mechanisms for overcoming various frictions between agents, is the subject of an extensive literature. This paper presents a review of recent work on security design and is organized around the applications of security design in various fields of finance starting with classic corporate finance applications such as capital structure and corporate governance, securitization, banking, the interaction of market and security design, as well as emerging applications such as fintech and sustainable finance.

Keywords: capital structure, corporate governance, securitization, banking, fintech, sustainability

JEL Classification: D4, D8, G2, G3, Q5

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1. Introduction

Security design deals with deriving optimal contractual mechanisms for overcoming various frictions between agents and is closely related to the topic of mechanism design, which is about designing procedures to achieve outcomes. Although securities are designed to serve varied purposes, the fundamental outcome that financial security design aims to achieve is allowing agents to move funds freely across time and space, which is equivalent to completing markets. In fact, talking about a theory of optimal security design requires that markets be incomplete because in a frictionless, complete market in which it is possible to trade a security with a payoff that is contingent on any conceivable event, the form of securities issued is rendered irrelevant by the possibility to replicate any payoff. This paper provides a review of recent work on security design, which is structured around its application to classic fields such as corporate finance and financial markets, as well as fields which have become more important in the last two decades. These include security design issues that have gained prominence around the financial crisis of 2007-2008 related to financial intermediation, securitization and complexity in financial markets, as well as issues related to current developments like fintech and sustainable finance. This review focuses on recent work on security design and is complementary to earlier surveys by Allen (1989), Allen and Winton (1995), Harris and Raviv (1992) and Duffie and Rahi (1995), but it also covers early foundational papers that have significantly influenced the literature. The introduction provides an informal overview of the paper, and detailed references are discussed under each section.

The literature at the intersection of corporate finance and security design is covered in Section 2, and a distinction is made between studies which consider security design issues related to corporate financing and those related to corporate governance. Section 2.1 focuses on how firms should finance their operations and how the cash flows generated by them should be allocated to their financiers. Within this corporate capital structure literature stream, security design is mainly concerned with the optimal allocation of cash flows. Theory suggests that optimal contracts should include all possible contingencies but this is rarely observed in practice. A large number of papers seek to explain the observed optimality of debt, a non-contingent security which offers investors a fixed return that is independent of the firm's cash flows. In contrast, securities such as equity have variable payoffs that depend on the realized cash flows of the firm and so are said to be contingent. The degree to which security payoffs depend on the underlying firm's cash flows and its interaction with potential information asymmetries regarding these cash flows is an important issue underlying security design. An important theory, the pecking order theory, explains the optimality of debt in terms of its lack of sensitivity to the issuer's private information. When insiders are relatively more informed, the optimal mode of financing favors the least informationally sensitive security, resulting in a cash, debt and equity financing preference order. Weakening or reversing the nature of this informational asymmetry also changes the optimal security, and can make informationally sensitive securities such as equity optimal. Further refinements of asymmetric information environments explored in the literature include allowing for multiple sources of cash flow uncertainty, and relaxing the assumption that agents know the probability distribution generating uncertain outcomes or, in other words, allowing for ambiguity.

Another prominent theoretical argument for the optimality of debt emphasizes the efficiency of monitoring, and highlights the idea that verification frictions prevent the introduction of contingencies in contracts. Given imperfect outcome or state verification, a number of papers focus on the role of manipulation in particular, while others assume that outcomes can be measured accurately and focus on designing securities that have payoffs which are made contingent on those outcomes. Contingent security designs discussed in the literature include performance-sensitive debt which has a face value that changes with a signal, or which has an interest rate that rises if the borrower's performance deteriorates and vice-versa. Moral hazard is another important friction that is relevant when considering security design in relation to corporate financing, and theoretical work in this area deals with how to design contracts so as to prevent agents from diverting cash flows or consume other private benefits. An ever growing number of papers derive capital structure implementations of optimal contracts obtained in dynamic principal-agent models of financial contracting.

Corporations can be viewed as a nexus of contracts between various economic agents. Securities are contracts that govern the relationships between these agents, so they effectively represent a form of corporate governance. Section 2.2 covers studies at the intersection of security design and corporate governance, where security design is mainly concerned with the allocation of voting or control rights. The allocation of control rights can be made with a view to govern the firm in the normal course of operations, or it has to do with governance in unfavorable states of the world. When it comes to managing the day to day operations of a firm, security design deals with the allocation of voting rights to different securities, such as one-share-one-vote, or the determination of voting rules, such as majority voting. The allocation of control rights during unfavorable states of the world involves the transfer of control rights from equity to debt holders, rather than allocation among equity holders. In this context, security design typically enables making the transfer of control contingent on the failure to make payments or on performance. When a firm near default such that its assets might fall short of fulfilling creditors' claims, the firm can either renegotiate its debt claims with creditors or bankruptcy can be triggered. The latter involves transferring control rights to debt holders who can either help reorganize the firm or liquidate it and allocate the proceeds to creditors according to seniority.

The allocation of control and/or cash flows rights is not only contingent on default but also on performance. Convertible securities are a way to implement performance-contingent rights allocation. Convertible securities are a special class of securities that covers a wide range of possibilities, but typically taking the form of debt or preferred stock, which embed an option to convert to common equity. Thus, there is conversion to securities that come with a different set of cash flow and voting rights. Convertible securities are particularly popular in the field of venture capital, a field which is special because it requires effort from both the financier and the borrower. Optimal security design in this double moral hazard environment has considered convertible securities that endogenously allocate rights as a function of the state of the world and the borrower's effort, depending on whether exit occurs by acquisition or IPO, in setups involving multiple investment stages and imperfect verifiability of continuation conditions into later stages.

Section 3 covers security design issues specific to financial intermediaries, a class of organizations that are special because of their low level of equity capital. It reviews proposals for contingent capital, which call for large financial institutions to issue a percentage of their long-term debt capital in the form of convertible debt securities that would automatically convert into equity as the issuing institution's financial condition weakened. Although the general idea underlying contingent capital instruments is the same, namely conversion to equity conditional on pre-specified capital related contingencies, the literature has proposed and discussed numerous features along which security designs can vary in the aftermath of the crisis. The capital conversion trigger, which is essentially a threshold triggering conversion to equity, can be based on accounting or market-based equity measures. Market-based triggers, in turn, can refer to a bank's overall market capitalization or its share price. Single triggers impose a capital condition reflecting a bank's own condition, whereas dual triggers can make conversion contingent on an institution-specific capital condition as well as an industry-wide condition. Conversion can award a fixed or a variable number of shares, can be to common or preferred equity, and there can also be variation with respect to the voting rights awarded. The conversion price can be fixed and pre-specified in the debt contract, or implied by the contemporaneous share market price.

Despite the advantages brought about by contingent convertible securities in terms of reducing effective leverage, the risk of a bankruptcy, and the justifications for a bailout, their issuance also comes with problems related to distorted incentives for equity holders to increase the level of risk, or to refrain from replenishing equity following declines, a phenomenon called debt overhang. Conversions based on market values can also create opportunities for manipulation by speculators who can purchase an issuing bank's contingent security and short its shares. Additionally, conversion ratios that dilute issuer's equity holders generate incentives to preemptively raise equity capital to avoid triggering conversion, and if value transfer between equity and debt holders is expected ex-ante, a unique equilibrium in equity or contingent capital prices may not exist.

Section 4 covers the design of securities governing the allocation of cash flows generated by underlying pools of assets rather than the allocation of cash flows generated by firms. In other words, it covers securitization, the process by which financial intermediaries create pools of financial assets and sell claims to the cash flows generated by these pools to various classes of investors. Security design in the context of securitization refers to the issues of pooling and tranching. Whereas pooling refers to the choice of financial assets to pool and sell to an entity called a special purpose vehicle (SPV), tranching deals with the choice of how to allocate the cash flows generated by the pool of assets to various categories of investors, which essentially refers to the capital structure of the SPV. Through pooling, privately informed sellers lose their information advantage, but pooling also has the effect of improving market liquidity because it decreases the amount of information relevant for valuing the asset-backed securities. Tranching enables separating the cash flows generated by the underlying assets and creating securities which have payoffs with varying degrees of sensitivity to the seller's private information. Tranching reduces underpricing losses and has implications for trading, as it allows issuers to mitigate adverse selection costs created by asymmetric information about asset values and non-verifiability of liquidation motives. Combining the risk diversification effect of pooling with the creation of securities that are less sensitive to the seller's private information makes the securitization design that involves pooling and tranching optimal. The optimality of issuing tranches of varying seniority and the ensuing senior/subordinated financial structure design is another subject that has been dealt with in the literature, and a relatively small number of studies also look into governance issues related to securitization, by tackling the question of which tranche should control liquidation and renegotiation. Theoretical predictions on the relative efficiency of subordinated security holders control are supported empirically.

A byproduct of securitization and structuring aimed at creating low-risk, liquid securities from collateral of variable quality, is complexity. Section 5 reviews work on security design complexity. Security design has implications for investor decision-making, so complex security designs are particularly important in retail markets populated by unsophisticated investors, conceptualized as boundedly rational agents that are limited in their ability to fully and rationally process information. The literature has characterized the ways in which price and product complexity are optimal responses of security designers competing for market power and profits. Empirical evidence suggests that more complex securities have a worse performance relative to simpler ones or even the risk-free asset, and that security designers tend to gain from increasing complexity. Other than increasing complexity with a view to profit, financial intermediaries create complex securities to cater to retail investors' yield-seeking behavior, their demand for safe assets or loss aversion, and more generally to the risk preferences of the main suppliers of capital. Regulating complexity in security design is not trivial. Simple reforms aimed at increasing information are likely to be unfruitful in markets populated by boundedly rational agents, and regulatory penalties are not easy to implement as they should take into account product characteristics and the financial institutions relative ability to control quality.

Section 6 reviews studies at the intersection of security and market design, which take into account the idea that the design of securities is not independent of the environment in which these securities are issued and traded. Given that the notion of optimal security design relies on markets being incomplete, a number of paper derive optimal securities given various frictions that make markets incomplete, such as transaction costs for issuing securities or marketing costs. Market incompleteness creates incentives for agents to innovate as value typically accrues to the innovators. The efficiency of security design, that is, whether security design leads to an efficient allocation of resources depends on who captures the profits from innovation. The literature has looked at incentives to introduce derivatives such as options and futures, as well as the implications of the availability of new hedging opportunities for trading and prices. The information transmission role of prices can have an adverse effect on risk-sharing, and whether new securities are issued and markets are optimally complete or incomplete depends on the effect of information revelation. Information frictions have not only been used to rationalize market incompleteness but also the existence of seemingly redundant securities, such as composite securities with values that are functions of the cash flows or values of other assets. Although these securities might seem redundant since investors can replicate them, their existence is justified if some investors possess inside information. Collateral frictions, imperfect competition and market segmentation are other important factors in relation to which financial innovation and security design have been studied. Market segmentation, in the sense of limited investor participation, creates incentives for strategic financial innovation and leads to endogenous asset structures. The optimality of financial market structures depends on whether financial innovation consists of the introduction of new assets into an economy without restricted participation, or the relaxation of restricted participation constraints for an existing asset. Market power is another important factor influencing security design, and research suggests that increasing market concentration through the introduction of exchanges tends to alter security design to the detriment of investors as it shifts market power to security designers.

Section 7 covers the implications of fintech for security design. The innovation at the heart of the fintech revolution is the blockchain, a type of distributed ledger which enables the keeping and sharing of records in a decentralized, transparent and verifiable way. Fintech has brought about new possibilities in corporate financing and a number of papers study the optimality of financing ventures through the issuance of digital tokens via Initial Coin Offerings (ICOs), versus traditional forms of financing such equity, debt, or venture capital. In an ICO a firm raises funds by issuing digital coins or tokens, to finance the development of a platform offering a new product or virtual currency. The optimal form of financing typically depends on the frictions considered, the key token features and the characteristics of the venture to be funded. Some of the key token features studied in the literature are utility features which enable using the token as a transaction medium on the platform, security features which grant cash flow rights or represent a claim on the platform's output. An issue related to token financing, which can render it inferior relative to traditional forms of financing, is the lack of commitment in new token issuance, which affects particularly platforms that intend to use those tokens as sole means of payment for their products. Simple token designs that grant rights to future economic output are suboptimal relative to equity financing, but tokens that embed a form of contingency offering investors a share in the revenues from the tokens issued after production are optimal. Studies at the intersection of fintech and corporate governance examine the blockchain innovation from the perspective of its interaction with existing corporate governance structures, as well as the new governance possibilities that it brings about. Additionally, the issue of governance of the blockchain itself is an important one, and under some but not all blockchain designs it is a function of security holdings. We discuss the relationship between consensus mechanism design and the allocation of control to the network users, and its dependence on token holdings.

The implications of blockchain technology for financial markets and trading are best understood in light of the fact that financial securities can be digitally represented. This enables the use of smart contracts as the basis for transference and has created the expectation that frictions in storing, recording and transferring digital securities will be eliminated. Although security digitization solves settlement uncertainty arising from limited commitment, it creates hold-up problems and even the breakdown of trade because intermediaries must purchase the securities in advance to facilitate a transaction. Ledger transparency raises privacy issues, leads to greater scope for collusion, can expose traders to the risk of front running, and thus affects competition and welfare.

Lastly, in Section 8 we review the literature at the intersection of security design and sustainable finance, a rapidly growing market comprising securities that finance projects aiming to reduce negative externalities or, alternatively stated, to generate public benefits. Traditionally, the funding of projects yielding public benefits has been pursued by public entities and has employed public money. A hybrid solution has combined public and private money and has taken the form of social impact bonds, securities designed to incentivize investors' participation by making returns increase with the social performance of the project funded. Recently, we see an increasing importance of purely private funding of projects that yield public benefits, through securities such as sustainability-linked bonds that have rates of return that decrease with the sustainability performance of the issuer. Thus, instead of investors being rewarded for funding projects yielding public benefits, we observe a regime which involves investors foregoing financial returns to incentivize firms to provide non-monetary benefits. Investments that have the potential to provide monetary as well as non-monetary benefits are affected by an agency conflict regarding which output to emphasize. Traditionally, corporate governance and shareholder activism have been tools used to balance profitability against social and environmental harm. Heterogenous investor groups, which mix financially and sustainability-oriented investors represent an implicit governance mechanism, so a number of papers explore the conditions under which investments by sustainability-oriented investors improve outcomes, as well as the optimal financing arrangements. The literature has also explored the role of security design in enforcing commitment by borrowers to deliver the sustainability benefits promised at security issuance. The optimality of security designs that make the cost of debt contingent on realized sustainability performance depends importantly on the presence of measurement frictions and the possibility of manipulating sustainability outcomes, commonly referred to as greenwashing.

2. Corporate Finance

An extensive literature studies security design from a corporate finance perspective, by focusing on issues such as corporate financing or capital structure (the allocation of cash flows) and corporate governance (the allocation of control rights). The firm is viewed as a nexus of contracts between various economic agents. Securities are contracts, and contracting can be complete and incomplete. According to theory, optimal contracts should include many contingencies that take account of all relevant information (Hart and Holmstrom, 1987). A number of papers explores various frictions that explain empirically observed departures from this theoretical prediction. Allen and Gale (1992) use measurement distortions and adverse selection to explain missing contingencies in optimal contracts in the context of a generic transaction between a buyer and a seller. When the measurement systems on which contingencies are based can be manipulated and agents differ in their ability to manipulate, non-contingent contracts are chosen in equilibrium because they do not reveal any information about the party proposing the contract. Holmstrom and Milgrom (1991) explain missing contingencies in employment contracts in a multitask principal-agent context in which a principal monitors multiple tasks with different precisions, while the agent's cost depends only on total effort and not on how effort is allocated. Fixed wages, i.e. non-contingent contracts, are optimal because increasing compensation for any one task creates incentives for the agent to reallocate effort away from the other competing tasks that are more difficult to measure and reward.

2.1 Capital Structure and the Allocation of Cash Flows

The capital structure literature deals with issues related to the financing of the firm and the subsequent allocation of cash flows generated by the firm. A distinction can be made between studies that take certain financial securities as given and analyze the optimal mix of securities to be issued in the face of frictions between agents, and those that derive financial securities as optimal mechanisms for overcoming various frictions between agents.[3] Cast in the context of firm financing, these two perspectives ask the questions: "what are the circumstances in which given securities such as debt and equity are optimal", and "what are the optimal securities that should be issued", respectively.

A large literature seeks to explain the observed prevalence of debt, a financing contract that promises to repay investors a fixed payoff that is independent of the firm's cash flows. Unlike debt, equity is a contract with variable payoffs that are said to be contingent in the sense that they depend on the firm's realized cash flows. An important class of frictions driving security design and capital structure choices are information frictions and the ensuing agency problems of adverse selection and moral hazard, which are conflicts arising because of misaligned incentives and goals of different parties.[4]

A leading theory for the optimality of debt is the pecking order theory going back Myers and Majluf (1984), in which adverse selection costs lead firms to finance investment with the least informationally sensitive security. Information sensitivity has to do with the dependence of a security's payoffs on the firm's realized cash flows. A security with high sensitivity to cash flows is also one that has a high sensitivity to information about these cash flows. So when insiders have negative private information about the firm's future cash flows, for example, securities such as equity that represent claims to residual cash flows suffer underpricing losses. Firms can reduce mispricing by issuing debt rather than equity because it is less sensitive to private information. In a multiple-firm equilibrium, issuing fixed claims is optimal because it minimizes cross-subsidies from high to low types, and as a consequence all firms pool at the non-contingent debt contract.

Noe (1988) denies the optimality of debt financing in all such settings and shows that there can exist equilibria in which both debt and equity are issued in equilibrium. This happens when insiders have imperfect information about the firm's future cash flows and they still face some residual uncertainty, with the implication that some firms separate and strictly prefer equity to debt. Nachman and Noe (1994) derive general conditions for the optimality of debt in a setup with asymmetric information and adverse selection. There is information asymmetry about the probability distribution of cash flows generated by the firm and market participants draw inference about the productivity types of security issuers from the contracts proposed. There is an adverse selection problem in that the security design of firms with low-productivity investment opportunities imitates those of firms with high productivity investment opportunities. Debt financing is a pooling equilibrium outcome if and only if firm productivity types can be ordered (by conditional stochastic dominance).

Models based on asymmetric information generally predict that securities with low sensitivity to private information, such as debt, dominate those with high information sensitivity, such as equity. The nature of the information asymmetry is one whereby firm insiders are relatively more informed than security buyers. However, when this assumption is relaxed the prediction regarding the optimal security changes. Rahi (1996) shows that with adverse selection and rational investors who use market prices to infer the private information of insiders, equity is optimal. With rational

[3] Allen (1989) and Allen and Winton (1995) refer to these two perspectives as the capital structure and the security design perspective, respectively.

[4] Adverse selection refers to a situation in which a principal delegating a task to an agent cannot freely observe or verify innate characteristics of the agent ex-ante, so there is asymmetric information ex-ante. With moral hazard, the information asymmetry has an ex-post nature and refers to situations in which the agents cannot freely observed actions or perfectly verify them ex-post.

investors the firm's informational advantage is forgone and the hedging motive remains the prevailing one. Equity is optimal because it allows efficient risk-sharing and the firm insiders have no privileged information. Worth noting is that if there were noise traders, the firm could exploit its superior information without compensating investors with a higher risk premium, so the preferred security would be one that preserves the informational advantage.

Fulghieri and Lukin (2001) study optimal security design and issuance under asymmetric information, in a setup in which outside investors can produce noisy information on the firm's quality. This results in an endogenous degree of information asymmetry that depends on the information sensitivity of the security issued. In contrast to the prediction of the pecking order theory, a security with low sensitivity to private information, such as debt, does not always dominate one with high information sensitivity, such as equity. Depending on the cost and precision of the information-production technology, risky debt or a composite security with a convex payoff emerge as optimal securities.

Axelson (2007) studies a capital structure problem in which the nature of the information asymmetry is reversed, and it is outside investors rather than managers that have superior information about the firm. This captures situations such as start-up companies seeking to raise funding from professional intermediaries like venture capital firms. In this setup, it is optimal for the firm to issue a security that is informationally sensitive, such as equity. Furthermore, the degree of competition among investors plays an important role when the firm has several assets that can back the securities issued. When competition is low, debt backed by a pool of assets is optimal, whereas equity backed by individual assets is optimal when competition is high.

Yang and Zeng (2018) study a setup in which investors can acquire information about the firm's project before providing financing. In this setup, investors benefit from information acquisition at the expense of the issuing firm, with the implication that the firm deliberately designs the security to induce investors to acquire the information that is least harmful to its interests. When the investor has the bargaining power in security design or can only acquire information after financing, the optimal security is equity. When bargaining power in security design is with the firm, the optimal security helps incentivize both efficient information acquisition and financing, and depends on the importance of information for production. When information is not very valuable, the optimal security is debt, whereas a combination of debt and equity is optimal when information is valuable. Inostroza and Tsoy (2022) show that when security issuers can design the structure of private signals that they receive at the trading stage, the optimal security design is pure equity. The standard result on the optimality of debt as the least informationally sensitive security only holds under additional restrictions on security or signal design.

Starting from the premise that a privately informed issuer's choice of what security to issue signals something about the issuer's quality, Daley, Green and Vanasco (2021) study the implications of an improved informational environment for the form of security designed and the amount of inefficient retention of cash flows. Scrutiny, which can take the form of either credit ratings, analyst reports, or mandatory disclosures, reduces information asymmetries and thus decreases issuers' reliance on retention to signal quality, which has the effect of increasing efficiency and decreasing price informativeness. When scrutiny is sufficiently intense, issuers will optimally design an informationally sensitive security such as equity. Otherwise, the optimal security design is a standard debt contract.

Liu and Bernhardt (2021) propose a target-initiated theory of takeovers where target firms approaching potential acquirers have an information disadvantage. Specifically, potential acquirers are privately informed about their standalone values and merger synergies, which are assumed to be positively related. The adverse selection problem faced by the target can be solved by having acquirers submit bids that combine securities with different levels of information sensitivity. Despite their informational disadvantage, targets can extract all surplus if the acquirer gets a stake in the firm through a combination of cash and equity, provided that synergies and standalone values are concavely related. However, when synergies and standalone values are not concavely related, targets can gain by offering payment choices that combine cash with securities that are more informationally sensitive than equity to underlying cash flows.

A related paper studying optimal security design for firm acquisition is Jansen, Noe, and Phalippou (2021), who consider a setup in which the nature of the information asymmetry is one in which insiders have the advantage. Specifically, they propose a model in which a potential acquirer approaches a firm with a value-added plan and the firm has private information that the acquirer will add less value than expected. Although the acquirer can choose any monotone limited liability security to offer along with cash, the optimal security through which the acquirer will get a stake in the firm is non-recourse junior debt.

Further asymmetric information refinements explored in the literature include accounting for multiple sources of cash flow uncertainty and relaxing the assumption that agents know the probability distribution generating these uncertain outcomes or, in other words, accounting for Knightian uncertainty or ambiguity. Fulghieri, Garcia and Hackbarth (2020) make a distinction between asymmetric information about assets in place versus growth opportunities. They find that when asymmetric information is concentrated on assets in place, equity-like securities (including convertible debt) are more likely to be optimal. However, when asymmetric information is about risky growth opportunities, debt is optimal. The model rationalizes why high-growth firms may prefer equity over debt financing, as it suggests that equity is more likely to dominate debt for younger, not yet well established firms with larger investment needs and more valuable growth opportunities.

Similarly, Malenko and Tsoy (2020) also distinguish between assets in place and growth opportunities, but they study the role of Knightian uncertainty or ambiguity, which means that agents are do not know the probability distribution governing uncertain outcomes but instead entertain the possibility of multiple such probabilities. Ambiguity-averse agents evaluate uncertain outcomes using the least favorable probability distribution of the set of contemplated distributions. Specifically, the firm is privately informed about the distribution of project cash flows but the investor faces Knightian uncertainty regarding them. If private information concerns assets in place, the equilibrium security is usually risky debt and equity is never issued. If private information concerns growth opportunities and uncertainty is sufficiently high, meaning that the project is contemplated to potentially have a negative NPV, the security issued in equilibrium is equity. However, if uncertainty is sufficiently small, meaning that the investor is confident that the new project has a positive NPV, the equilibrium typically features risky debt.

Another important friction that the literature has considered when studying security design is moral hazard (Innes, 1990). Hébert (2018) studies static and dynamic security design in a setup with moral hazard and shows that debt securities minimize the welfare losses associated with excessive risk taking and lax effort. For any security design, the variance of the security payoff is a statistic that summarizes these welfare losses. Among all limited liability securities with the same expected value, debt securities have the least variance. Mixtures of debt and equity are exactly optimal, and pure debt securities are approximately optimal. Carroll (2015) proposes a principal-agent model in which an ambiguity-averse principal that faces uncertainty about the set of actions taken by the agent and proposes a contract meant to guarantee a positive expected payoff. The optimal contract is linear, and pays the agent a fixed share of the output. While many other contracts can provide a positive guarantee, the best such guarantee comes from a linear contract.

An important class of moral hazard manifestations such as the possibility that agents divert cash flows or consume other private benefits is studied by DeMarzo and Fishman (2007), who derive debt and equity as optimal securities in a discrete-time principal-agent model of financial contracting. The optimal contract is a complicated mechanism specifying the payments between the firm and investors, as well as the conditions under which the project is terminated. However, this mechanism can be implemented with a combination of common securities, namely equity, long-term debt, and a line of credit. Biais, Mariotti, Plantin and Rochet (2007) derive the continuous-time limit of a stationary version of DeMarzo and Fishman (2007) and consider an alternative implementation of the optimal contract in which the firm uses cash reserves instead of the credit line.

DeMarzo and Sannikov (2007) provide a continuous-time extension to the agency model of DeMarzo and Fishman (2007), and examine the properties of the credit line, long-term debt, and equity that implement the contract. They note that in a dynamic context the usual conflicts between debt and equity need not arise. Specifically, the use of leverage does not create incentives for equity holders to increase risk so that there is no asset substitution. Additionally, there is no strategic default, as equity holders have no incentive to either precipitate default by paying dividends or postpone default by contributing new capital. When the risk of loss from the project is severe, in addition to debt, equity, and a credit line, the optimal contract may require that firms hold a compensating cash balance as a requirement for the credit line.

Miao and Rivera (2016) build on the DeMarzo and Sannikov (2007) continuous-time agency model with hidden action and consider a situation in which the principal has ambiguous beliefs about mean project cash flows. The optimal contract is implemented using debt, equity and cash reserves, as in Biais et al. (2007), and a form of contingency arises as a consequence of ambiguity. The payoffs to equity holders consist of ordinary dividends when cash reserves reach a threshold level, as well as special dividends or cash injections which arise as a hedge against model uncertainty and to smooth dividends. Ling, Miao and Wang (2021) study financial contracting in an agency model with investors that face ambiguity about the mean firm productivity. The ambiguity-robust contract can be implemented by choosing a capital structure with a mix of debt, equity, cash, and dynamically trading a derivative contingent on the firm's output. The financial derivative asset arises as a hedge against the investors' concern that the entrepreneur may be overly optimistic.

Hansen (2021) studies the implications of ambiguity about cash flow volatility in the context of a model of optimal contracting under moral hazard. Relative to the implementation in DeMarzo and Sannikov (2007) the optimal credit limit increases and the face value of debt increases with ambiguity. Relative to the cash-based implementation of Biais et al. (2007) the cash buffer that the firm accumulates before paying dividends to equity holders increases with ambiguity. Thus, the maximum financial slack that the firm is given under the optimal contract increases with the level of ambiguity aversion in both the credit line implementation and the cash-based implementation.

Another departure from the rational expectations paradigm, which has been used to rationalize the optimality of debt, is adaptive learning. Noe, Rebello and Wang (2003) study corporate security issuance in an economy populated by adaptive agents who learn through experience about the structure of security returns and prices. The idea behind adaptive learning is that each agent gravitates toward strategies that generate the highest payoffs through a process of evolutionary selection. A firm is more likely to issue a security and the security's underpricing is smaller, the smaller the probability of loss to investors. A financing hierarchy emerges in which straight debt dominates other financing choices, while equity and convertible debt display significant underpricing.

Another prominent theoretical argument for the optimality of debt, emphasizes the efficiency of monitoring (Townsend, 1979; Diamond 1984; Gale and Hellwig, 1985). Townsend (1979) explains the optimality of standard debt contracts in terms of costly state verification. In this model, agents are asymmetrically informed on the realization of some random endowment but this information may be transmitted to other agents at some cost. A contract is a pre-state agreement that specifies when there is to be verification and the amount to be exchanged. The optimal contract has debt-like features in the sense that in good states no verification occurs and the borrowing agent makes a certain fixed pre-specified payment. Verification occurs only in bad states when output is sufficiently low, and the payment to the lender is lower than in the non-verification state.

Harris and Raviv (1995) study endogenous securities conceptualized as games in a setup in which verification frictions prevent the introduction of contingencies in contracts. The idea behind contracts as games is that of endogenous contract determination: the contracts specify the procedures that govern the behavior of contract participants in determining outcomes as well as the allocations resulting from those outcomes. When the outcome on which contingencies depend cannot be verified, contracts designed as games can improve the allocation of resources relative to nonstrategic allocation rules.

Building on the idea of imperfect outcome or state verification, a number of papers focus on the role of manipulation in particular. Lacker and Weinberg (1989) study a model of ex-post moral hazard where profit manipulation opportunities move optimal contracts from debt toward equity-like arrangements.[5] Koufopoulos, Kozhan and Trigilia (2019) derive necessary and sufficient conditions for the optimality of straight debt in an asymmetric information setup in which firms can engage in profit manipulation. Contrary to conventional wisdom, debt is often suboptimal, and it is never uniquely optimal. Contracts involving profit manipulation in equilibrium allow the implementation of allocations that cannot be achieved otherwise. Optimal contracts are non-monotonic and can be implemented as performance-sensitive debt, meaning that they pay the face value and potentially a bonus whenever the firm does not default on its debt.

Chaigneau, Edmans and Gottlieb (2021) note that an assumption that has been critical in generating debt as the optimal contract is the reliance on a single contractible measure of performance. They consider an additional signal that is informative about the agent's effort and ask whether and how the optimal contract changes if principal has access to this additional signal. While debt remains the optimal security, additional signals affect the face value of debt. The paper provides a theory

[5] Related work that explicitly models profit manipulation opportunities includes Picard (2000) in the context of insurance, Crocker and Slemrod (2007) in the context of managerial compensation, Strobl and Povel (2013) in the context of cost of capital, and Guttman and Marinovic (2017) in the context of debt and covenants violations.

of performance-sensitive debt (PSD), defined as debt which has a face value that changes with a signal, and shows how the face value should depend on other signals.

Manso, Strulovici and Tchistyi (2010) study performance-sensitive debt (PSD) modelled as debt that gives investors the right to charge a higher interest rate if the borrower performance deteriorates and vice-versa. PSD contracts are sub-optimal when there is perfect information about firm types and bankruptcy is costly, yet they become optimal with asymmetric information as they are used as an investor's device for screening good types. Importantly, performance is assumed to be captured using a precise performance measure. The model predicts that there exist separating equilibria in which high-growth firms issue a risk-compensating PSD security, while low-growth firms issue fixed-interest debt. Empirical support is given to this screening hypothesis, since borrowers with loans that have performance-pricing provisions are found to be more likely to be upgraded and less likely to be downgraded one year after the closing date of the loan, relative to borrowers with fixed-interest loans.

Begley (2012) also provides empirical evidence suggestive of the fact that good borrowers use PSD contracts to alleviate financial constraints. In line with the idea that contract design is used as a costly signal by good firm types to separate themselves from bad borrowers, this paper documents that PSD issuers receive larger loans, lower spreads and are less likely to experience financial distress. The paper exploits the convexity of the pricing grid in Dealscan, whereby interest rate increases associated with decreasing performance are higher than interest rate decreases associated with increasing performance. The performance metrics underlying the pricing grid are accounting ratios as well as credit ratings.

Asquith, Beatty, and Weber (2005) study how adverse selection and moral hazard impact interest-increasing and interest-decreasing performance pricing. The paper documents that interest-increasing performance pricing, which involves increasing spreads if credit quality deteriorates, is more common when moral hazard[6] costs are higher and downgrades are more likely. On the other hand, interest-decreasing performance pricing is more common when adverse selection[7] costs are higher, prepayment is more likely, and less common when multiple performance measures better predict credit quality.

2.2 Corporate Governance and the Allocation of Control Rights

Whereas the literature at the intersection of security design and capital structure focuses mainly on managers' incentives and the allocation of cash flows, the literature studying security design in relation to corporate governance focuses on investors' incentives and the allocation of control rights. In this context, optimal securities are essentially a form of corporate governance.

The study of the allocation of control rights is based on the incomplete contracts paradigm pioneered by Grossman and Hart (1986) and Hart and Moore (1988, 1990), which is concerned with the idea that in dynamic relationships, eventualities arise upon which parties cannot contract. In other words, it deals with unanticipated contingencies or the occurrence of events that the parties could not foresee at the time of signing or entering the contract. Also known as the property rights

[6] Moral hazard problems exist in debt contracts when borrowing firm has an incentive to shift wealth from lenders to shareholders either by increasing the risk of new investments or by altering dividend or financing policies.
[7] Adverse selection refers to situation in which asymmetric information between the borrower and lender results in a misclassification of credit risk, since borrowers cannot credibly and verifiably reveal private information about their future performance.

theory, it focuses on residual control rights by studying who has the right to decide about events that are left out from contracts. An application of property rights theory to the financial capital structure of a firm deals with studying the transfer of residual control rights as a way to protect investors against potential opportunistic behavior on behalf of managers. Hart and Moore (1998) emphasizes the role of debt in persuading an entrepreneur to pay out cash flows rather than divert them. In a context in which monetary returns are transferable and not verifiable, such that the manager can walk off with them, debt can be a bonding device. Control shifts to the investor if a debt payment is not made, so the manager is motivated to make the payment because of the threat that investors can seize the assets underlining the project and liquidate them. The model first assumes the optimality of the debt contract in order to show the importance of renegotiation and liquidation rights. The second part of the model revisits the assumption on the optimality of debt, and finds that debt is the optimal contract under reasonable assumptions. The empirical literature on leverage buyouts confirms the disciplinary role of debt, by providing evidence that high leverage and concentrated ownership provide powerful incentives for managers to perform (see Roberts and Sufi (2009b) and references therein).

Aghion and Bolton (1992) develop a theory of capital structure based on control rights, show that optimal control is state contingent and outline the optimality properties of the control allocation induced by standard debt financing. The optimal allocation of control rights is studied in a setup in which the firm manager has pecuniary and non-pecuniary motives, while the investor only pecuniary. The nature of the contingent allocation of control is that the investor will have control in states of the world where profits are important relative to private benefits to the manager, and the manager in states of the world where private benefits are important relative to profits. The shift of control does not occur as a result of the manager's failure to make a promised payment, but because of a particular state of the world occurring. Kaplan and Strömberg (2003) provide a detailed analysis of control allocation in 100 venture capital contracts. Their analysis highlights the prevalence of contingent control allocations, by documenting that control and liquidation rights are contingent on performance, and that control also shifts between constituencies depending on performance.

The allocation of control rights can be studied from the perspective of how voting rights should be assigned to securities, with implications in terms of how the firm should manage its day to day operations. Building on the premise that a firm with securities that are widely held is effectively run by a so-called incumbent management, Grossman and Hart (1988) consider a model where the allocation of voting rights and dividends to securities is determined by its effect on allowing rivals to obtain control from the incumbent management. In this corporate control contest, the optimal allocation depends on the absolute and relative private benefits accruing to the incumbent management team and the rival team. If private benefits are negligible or one-sided, the optimal allocation is one-share-one-vote. If private benefits are two-sided, separating votes from dividends is optimal.

Harris and Raviv (1988) also consider the optimal allocation of voting rights and dividends to securities, but their notion of optimality extends beyond what is privately optimal from the point of view of the firm owner. The paper considers the notion of social optimality, which also accounts for the private benefits to the incumbent and rival management teams. It is shown that the privately and socially optimal allocations are not the same. One-share-one-vote is socially optimal because it ensures that the management team that generates the greatest total benefits, consisting of shareholder compensation as well as private benefits to managers, controls the firm. The privately optimal allocation is that of issuing two extreme classes of securities, one with all the voting right and one with all the dividends.

Private benefits of control create incentives to acquire control even when this reduces firm value, thus giving rise to a conflict of interest between contestants for control and investors. Harris and Raviv (1989) study the role of security design in resolving this conflict of interest, demonstrate that the optimal security is a single voting security and generalize the result on the optimality of one-share-one-vote.

Zender (1991) examines the optimality of various voting rules for electing controlling management and derives conditions under which the simple majority voting rule and one share-one vote constitute a socially optimal corporate governance rule. Equity and debt are derived as optimal securities in a model in which cash flows and control rights are allocated endogenously. A debt holder's cash flows are fixed in order to provide the equity holder in charge of making investment decisions with efficient incentives for investment. Transferring the ownership of control to the debt holder attenuates the impact that asymmetric information concerning investment opportunities has on the efficiency of decision making.

Boot and Thakor (2011) study how the design of control rights granted to new investors interacts with firm security choice and capital structure in a setup in which insiders may disagree with external financiers over project choice. Their model predicts that financial claims that maximize managerial project-choice autonomy are ex-ante preferred by management. A dynamic pecking order of cash, equity, and debt emerges. Control rights given to investors depend endogenously on the security issued and on the amount of cash accumulated by the firm.

While the allocation of voting rights to various classes of shares is made with a view to govern the firm in the normal course of operations, the transfer of control rights to debt holders has to do with governance in unfavorable states of the world. Debt is rationalized as a mechanism for transferring control to creditors in states of the world in which the firm nears bankruptcy or, in other words, situations in which assets might not be sufficient to fulfill debtors' claims. When that is the case, debt claims can either be renegotiated, or bankruptcy can be triggered, which involves transferring control rights to debt holders who can help reorganize the firm, or liquidate it and allocate the proceeds to creditors according to seniority. Thus, dividing control with creditors, or more generally fixed claim holders, is rationalized in terms of the threat of liquidation if performance is poor (see the review by Becht, Bolton and Röell (2003) and references therein).

Robustness to renegotiations is another prominent theoretical argument for the optimality of debt (Hermalin and Katz, 1991; Dewatripont, Legros and Matthews, 2003). Contract renegotiation may prevent the implementation of the first-best outcome when investments are observable but unverifiable. However, Aghion, Dewatripont, and Rey (1994) show that if the initial contract is able to monitor the ex-post renegotiation process, efficient investment and optimal risk-sharing can be achieved. In this model the parties are able to control the renegotiation process contractually, in the sense that the assignment of ex-post bargaining power is specified in the contract rather than being given exogenously. The features of renegotiation design that they focus on are default options in case renegotiation breaks down, and the allocation of all bargaining power to either contracting party. These two features can be obtained through contractual provisions such as specific-performance clauses and penalties for delay.

Roberts and Sufi (2009a) provide empirical evidence that over 90% of long-term debt contracts are renegotiated prior to their stated maturity, and this is rarely a consequence of distress or default.

Contingencies are found to play an important role in renegotiations, as renegotiation is partially controlled by the contractual assignment of bargaining power which happens in a state contingent manner. In light with the observed prevalence of debt contract renegotiation, a number of theoretical papers distinguish between types of debt according to the ease of renegotiating these contracts. Hackbarth, Hennessy, and Leland (2007) assume that there are two types of debt, market debt and bank debt, which differ with respect to the ease of renegotiation. Bank debt can be costlessly and efficiently renegotiated, while market debt cannot be renegotiated at all. Ideally, firms would only contract bank debt, but that claim is limited by their collateral value so firms take out market debt in order to increase debt-capacity. The paper shows in particular, that optimally both types of debt coexist.

Repullo and Suarez (1998) characterize the circumstances under which a mixture of bank and market finance is optimal, where the two forms of debt are conceptualized as informed and uninformed finance, respectively. Informed lenders are assumed to be able to observe the entrepreneur's level of effort at a certain cost and although they cannot use this information to enforce a contingent contract, it enables them to liquidate the project. So the key role of informed finance in the moral hazard context studied here is the threat of liquidation. The possibility of collusion between the entrepreneur and their informed lenders means that they can renegotiate their share of continuation proceeds after the effort decision has been made, and has the implication of making first-best effort not attainable. This renegotiation possibility determines the form of the optimal three-party contract. In order to give the informed lender the right incentives to liquidate, informed debt will be secured and senior to uninformed debt, and in the optimal renegotiation-proof contract uninformed debt will be obtained only after informed debt capacity has been exhausted. This paper rationalizes why informed bank debt is typically secured, senior, and tightly held.

An important issue when it comes to bankruptcy has to do with allocating the proceeds obtained from the liquidation of the firm’s assets to the various classes of creditors, which is done according to creditor seniority. Winton (1995) provides a theoretical rationale for seniority and absolute priority for senior investors in the context of a model in which a firm contracts with multiple investors and the firm’s output can only be privately verified at a cost. The model predicts an ordering of monitoring activities among investors, which are reactions to financial distress and can therefore be interpreted as gradual bankruptcy provisions.

Anderson and Sundaresan (1996) study the design and valuation of debt contracts in a general dynamic setting with uncertainty, where bankruptcy is determined by the terms of a debt contract and applicable bankruptcy laws. Debt holders and equity holders are non-cooperative and the firm reorganization boundary is endogenously determined. The model predicts deviations from absolute priority and forced liquidations along the equilibrium path. Strategic debt service has the effect of significantly increasing default premia, even when liquidation costs are small. When firms have a higher cash payout ratio, the security design tends to stress higher coupons and sinking funds.

Unlike most papers studying bankruptcy while taking the firm’s capital structure as given, von Thadden, Berglöf and Roland (2010) study the joint design of bankruptcy and debt contracts, and account for the fact that the bankruptcy procedure has an impact on the firm’s capital structure decision. The model makes a distinction between debt collection, which refers to the bilateral debt claim settlement between a creditor and the debtor, and bankruptcy, which is conceptualized as collective debt collection. When existing claims are inconsistent in the sense that their sum is larger than the available amount of verifiable assets, the debtor cannot fulfill them all and the role of bankruptcy is to adjust individual claims. It is shown that each creditor's right to liquidate assets, which protects him against opportunism by the debtor, must be complemented by the right to trigger bankruptcy, which in turn limits the individual liquidation rights because bankruptcy implies an automatic stay. It is optimal to give the debtor the right to trigger bankruptcy in circumstances in which giving the creditors the right to trigger bankruptcy is not sufficient to rule out runs for the assets. The model also predicts that the debtor should, under certain circumstances, violate absolute priority by retaining some of the assets in bankruptcy, and all creditors should optimally be treated symmetrically ex-post, in the sense that either all creditors are repaid or all are defaulted upon.

Antill and Grenadier (2019) consider a realistic continuous-time dynamic bargaining model of optimal capital choice and bankruptcy choice, in which firms can choose to enter either Chapter 11 reorganization or Chapter 7 liquidation. Chapter 11 reorganization can be thought of as a bargaining process between the firm and creditors who share control, the firm may continue operating and issue new debt, but there is a decline in cash flows and reorganization costs are incurred. Both debtors and creditors face uncertainty as they propose, bargain and accept reorganization plans. On the other hand, under Chapter 7 liquidation equity holders receive nothing, so Chapter 11 is optimal for equity holders only if the firm is sufficiently profitable at the moment of default. Equity holders can choose both their timing of default and the chapter of bankruptcy, and this is priced by creditors into ex-ante credit spreads. When reorganization is less efficient than liquidation, the added option of reorganization can actually make equity holders worse off ex-ante, even with liquidation in equilibrium.

Roberts and Sufi (2009b) provides a survey of the empirical evidence on bankruptcy and restructuring, which overwhelmingly supports the hypothesis in theoretical financial contracting research that debt represents a powerful control rights transfer mechanism in cases of payment default. Evidence also points to the efficiency of creditor control, as studies suggest that creditor control in bankruptcy improves firm value. Creditor control is strong also outside bankruptcy, and is manifested as creditors beginning to exert control even before payment default. It is the holders of private debt that enjoy broad powers through the use of covenants in private credit agreements such as syndicated secured term loans and revolving credit facilities. So creditors play a crucial role in corporate governance, and it is not only the board of directors that exerts significant control over corporate decisions outside of bankruptcy. Creditors obtain and exert control over important financial and real decisions even in the absence of payment default, and this has real effects.

A special class of securities that allow for contingent allocation of cash-flow and control rights are convertible securities, which are typically bonds or preferred stock that can be converted into common stock. The most common type of convertible security is debt that can be converted to equity, followed by convertible preferred stocks, which are hybrid securities with features of both debt and equity, in that they have a higher claim on distributions as well as an option to convert to common equity with voting rights and participation in price appreciation.

Basak, Makarov, Shapiro, and Subrahmanyam (2020) provide a status-based explanation for convertible securities. They propose a dynamic model for examining security design under non-standard preferences that capture status concerns, which means that entrepreneurs exhibit risk aversion when their status is low or high, and risk seeking behavior when wealth is between levels associated with low and high status. The optimal security is similar to a convertible security, in that it features equity- and debt-like components, with the debt-like component emerging so as to compensate the risk-averse financier from the status-induced increase in firm riskiness which occurs when high status is in sight. Incentives to issue convertibles increase with volatility and dynamic flexibility, and so the model rationalizes why convertible securities are mainly issued by riskier and more flexible firms.

The use of convertible securities is particular prevalent in venture capital (VC), a field that is special because the active involvement of both the entrepreneur and the venture capitalist is required for the ultimate success of a joint venture. This situation in which both the entrepreneur as well as the financier need to exert value adding effort has been modelled as a double moral hazard problem.

Schmidt (2003) demonstrates that convertible securities represent a powerful incentive mechanism in a sequential double moral hazard problem and can be used to induce both parties to exert effort efficiently. Convertible securities can give the venture capitalist the option to convert a debt claim into some fraction of the equity of the firm and it can be used to endogenously allocate cash-flow rights as a function of the state of the world and the entrepreneur's effort. This enables the entrepreneur and the venture capitalist to invest efficiently in the project and this design is robust to renegotiation. A suitably chosen convertible security strictly outperforms any standard debt-equity contract.

Hellman (2006) provides an explanation for the use of convertible securities in venture capital by studying a model with double moral hazard in which an important role is played by the form of exit. The paper studies in particular preferred equity that allocates different cash flow rights depending on whether exit occurs by acquisition or IPO. The model predicts that the optimal contract gives the venture capitalist more cash flow rights in the event of exit by acquisitions rather than IPOs, and contingent control rights are important for achieving efficient exit decisions.

Repullo and Suarez (2004) characterize the optimal securities for venture capital finance in a double-sided moral hazard environment with multiple investment stages. An important role in determining the optimal security is represented by the ability to verify continuation into later stage. If the conditions relevant for continuation are verifiable, the optimal security gives the venture capitalist a constant share in the success return of the project over a predetermined set of continuation states. However, if the continuation conditions are not verifiable the parties sign an initial start-up contract that is later renegotiated; the optimal start-up security gives a zero payoff in low profitability states and thereafter an increasing share in the success return of the project.

3. Banking

The capital structure of financial intermediaries (FIs), and in particular their low level of equity financing, makes the subject of an extensive academic literature as well as numerous regulatory debates. FIs have considerably lower level of equity financing, or so-called capital, compared to other types of corporations, which means that relatively small losses are amplified by leverage and can result in an FI’s bankruptcy, an event that poses significant problems to the real economy and has been the rationale behind much debated government bailouts. Given the severe negative implications of FIs’ failure, special attention has traditionally been given to safety and solvency regulation, with bank capital requirements coming under particularly intense scrutiny in the aftermath of the so-called Great Financial Crisis of 2007-2009. In addition to increased capital requirements, which have the benefit of moderating the amplification of losses caused by leverage and providing a bigger buffer to absorb losses, a special topic related to the capital structure of FIs has been contingent or convertible capital.

The general idea behind contingent capital is that the FI would issue a percentage of its long-term debt capital in the form of a convertible debt security that would automatically convert into equity as the FI's financial condition weakened. Contingent capital instruments, first proposed by Flannery (2005), can be conceptualized as pre-planned contracts meant to stabilize large FIs by restoring their regulatory capital and improving their loss-absorption capacity. These instruments rest on rules specifying when new equity is required, thus replacing supervisory discretion about capital adequacy, and addressing the debt overhang problem which refers to the reluctance of overleveraged FIs to issue new shares and replenish equity after a decline. It has generally been agreed that contingent capital should reduce effective leverage, the risk of a bankruptcy, and the justifications for a bailout, thus insulating taxpayers from incurring FIs' private investment losses.

Under Basel III, compliant contingent capital instruments are triggered if a regulatory capital ratio drops below a given threshold. The most popular contract designs are principal write-down bonds and contingent convertibles, known as CoCos. Principal write-down bonds offer a reduction of the principal in case of a trigger event, and represent 55% of the current issuances (Avdjiev, Bogdanova, Bolton, Jiang and Kartasheva, 2020). The remaining issuances consist of CoCos that convert into equity when triggered. In other words, the converted amount can be equal to the full value of the convertible security, or there can be a conversion write-down involving a discount from the security's face value.

While the general idea underlying this class of instruments is the same, namely conversion to equity capital conditional on pre-specified capital related contingencies, there are several dimensions along which the design of these instruments can vary. The capital conversion trigger, which is essentially a threshold triggering conversion to equity, can be based on accounting equity measures or can be expressed in terms of the market value of equity. Market-based triggers, in turn, can refer to an FI's overall market capitalization or its share price. Single triggers impose a capital condition reflecting an FI's own condition, whereas dual triggers can make conversion contingent on an FI-specific capital condition as well as an overall, industry-specific condition. Conversion can be to common or preferred equity, and there can also be variation with respect to the voting rights awarded. The conversion can award a fixed or a variable number of shares, or it can be specified to result in a fixed dollar amount of shares. The conversion price can be fixed and pre-specified in the debt contract, or it can be variable and typically implied by the contemporaneous share market price.

The literature has discussed various designs for contingent capital, as well as issues related to the effect of contingent capital instruments on bank and financial sector stability, risk taking incentives, and corporate governance. Flannery (2005) was the first to propose a form of contingent debt called reverse convertible debentures (RCD) that would automatically convert to common equity if a bank's market capital ratio were to fall below some stated value. Unlike conventional convertible bonds, these would convert at the stock's current market price rather than an absolute price specified in the agreement, thus forcing equity holders to bear the full cost of their risk-taking decisions. They would provide a transparent mechanism for un-levering a firm were the need to arise, and expose RCD investors to very limited credit risk under plausible conditions. Flannery (2017) discusses a number of important aspects that must be taken into account when designing so-called contingent capital certificates, and concludes that supervisors should define a set of basic features that qualifying convertible debt should have but let market participants design the specifics. Doing so would allow the optimal contract to vary over time and take account of current pricing and liquidity market conditions.

Coffee (2010) makes a case for contingent capital which would involve conversion to a senior, non-convertible preferred stock with cumulative dividends and voting rights. The design advocated here seeks to protect debt holders from loss on conversion by requiring that the conversion ratio would be deliberately designed to dilute the existing equity holders. Additionally, the debt security would convert into a fixed return preferred stock with cumulative arrearages and significant voting rights. In addition to stabilizing the FI and avoiding bankruptcy, the purpose of this security design would be to create a countervailing voting constituency to offset the voting power of risk-tolerant common shareholders.

McDonald (2010) discusses the mechanics for specifying the conversion ratio and focuses on single or dual price trigger specifications in particular. The paper proposes a form of contingent capital which converts debt to equity if the bank's stock price is at or below a trigger value, as well as if the value of an index capturing the health of the overall financial institutions at large is at or below a trigger value. This dual price trigger protects the FI during bad times when the entire industry does poorly, but permits failure of underperforming banks during normal times. The paper also discusses issues related to contingent capital such as susceptibility to manipulation, whether conversion should be for a fixed dollar amount of shares or a fixed number of shares, the susceptibility of different contingent capital schemes to under and over-capitalization errors, and the losses likely to be incurred by equity holders upon the imposition of a requirement for contingent capital. Glasserman and Nouri (2012) examine contingent capital with a capital-ratio trigger based on accounting values, and with a partial and ongoing conversion process, which means that just enough debt is converted to equity every time the conversion threshold is reached and until the contingent capital is depleted.

Bolton and Samama (2012) propose a design for contingent capital, called capital access bonds, that is meant to eliminate the problems caused by automatic triggers. This design entails purchasing a collateralized option to issue new equity at a pre-specified strike price, so long-term investors are effectively selling the issuers rights to issue equity in crisis events at a pre-specified price. Rather than being a substitute for bankruptcy, this security would act as a capital line commitment to banks. The paper argues that the issuance of this type of security stands to benefit all the parties involved by balancing investors' preferences, issuers' constraints, and regulators' objectives. Banks benefit because they effectively purchase insurance and can ensure that they will have sufficient regulatory capital available when they need it most. Long-term investors can obtain an adequate return by monetizing their counter-cyclical investments strategies in banks, and regulators can implement a more transparent and flexible form of equity capital regulation.

Albeit limited, there is empirical evidence that these securities do bring about the purported stabilization benefits. Vallée (2019) empirically investigates the effects of banks triggering contingent capital instruments by studying liability management exercises by European banks, which bear comparable regulatory capital effects. These exercises allowed banks to book capital gains on their liabilities as core tier 1 capital, therefore propping up their most scrutinized regulatory capital ratio. The findings are consistent with these exercises being effective at improving bank capitalization levels and strengthen the case for contingent capital instruments as an alternative to raising bank capital requirements. The market reaction to liability management exercises is positive and the created value mainly accrues to debt holders.

Avdjiev, Bogdanova, Bolton, Jiang and Kartasheva (2020) undertake the first comprehensive empirical analysis of bank contingent convertible (CoCo) issues, a market segment consisting of over 730 instruments totaling $521 billion issued between 2009 and 2015. They document that larger and better capitalized banks are more likely to issue CoCos, and issuing CoCos has the effect of reducing the issuers' credit default swap (CDS) spreads in line with the idea that CoCos generate risk-reduction benefits and lower the cost of debt. This is especially true for CoCos that have automatic triggers, whereas CoCos with only discretionary triggers do not have a significant impact on CDS spreads. In terms of stock market reactions, issuing CoCos has no statistically significant impact on stock prices, except in the case of principal write-down securities with a high trigger level, where a positive effect is observed.

While having a number of advantages, the issuance of contingent capital also comes with problems related to distorted incentives for equity holders to increase the level of risk, and to refrain from replenishing the equity of highly leveraged FIs following declines, a phenomenon called debt overhang. Additionally, conversions based on market values can create opportunities for manipulation. For instance, speculators can purchase an issuer's contingent security and short its shares. If the share price is reduced by short sales, conversion of the contingent security at an advantageous (temporarily low) price would give the speculator a capital gain on the converted shares when the short sales are reversed. A pre-specified conversion price would circumvent the market manipulation issue but comes with its own shortcomings, so the literature has proposed more complicated security designs that still take into account market signals and conditions but are more robust to market manipulation. Pennacchi, Vermaelen and Wolff (2014) propose a so-called Call Option Enhanced Reverse Convertible (COERC), which contains an option to repurchase the newly converted securities. Under this security design, the bond converts to equity when the market value of capital falls below a certain trigger but the conversion price is set significantly below the trigger price and, at the same time, equity holders have the option to buy back the shares from the bond holders at the conversion price. The COERC is meant to eliminate concerns of an equity price "death spiral" as a result of manipulation or panic, reduces the issuing FI's incentive to choose investments that are subject to large losses, and reduces the problem of debt overhang.

Implementation issues are highlighted by Albul, Jaffee and Tchistyi (2015), who develop a valuation model for contingent convertible bonds with market-based conversion triggers and derive conditions under which equilibrium is unique. Although contingent convertible bonds can increase bank value and reduce the probability of costly bankruptcy or bailout if properly implemented, issues related to debt overhang and manipulation exist. Specifically, incentives to manipulate the stock market exist when the conversion value is too low or too high. Substituting conventional debt for CoCos is likely to be resisted by highly leveraged and systemically important banks due to the debt overhang effect and the loss of the government subsidy. Goncharenko, Ongena and Rauf (2020) provide empirical evidence consistent with the idea that debt overhang affects a financial institution's willingness to issue CoCos. They document that riskier banks are less likely to issue CoCos, conditional on having CoCos outstanding are less likely to issue equity, and prefer issuing equity over CoCos. This is in line with the idea that riskier banks which have more volatile assets suffer from more debt overhang and resist issuing CoCos.

Sundaresan and Wang (2015) also raise concerns that contingent capital proposals do not in general lead to a unique equilibrium in equity or contingent capital prices. Specifically, they show that contingent capital with a market trigger, which leaves stakeholders unable to choose optimal conversion policies, does not lead to a unique competitive equilibrium if value transfer at conversion is expected ex-ante. However, this problem would be largely mitigated, and contingent capital would become implementable if the bond had a floating coupon rate, set at the risk-free rate.

Berg and Kaserer (2015) explore risk-taking incentives induced by contingent capital, focusing in particular on the effect of the conversion price of CoCos on equity holders' incentives. They theoretically show that when conversion transfers wealth from CoCo bond holders to equity holders, the latter's incentives to increase the riskiness of assets increase, while their incentives to raise new equity in a crisis decrease. Empirically, they present evidence that almost all existing CoCo bonds are designed in a way that implies a wealth transfer from CoCo bond holders to equity holders at conversion, and this contractual design is reflected in the prices at which these bonds are traded (as they are short volatility with a magnitude five times greater than that which can be observed for straight bonds).

Pennacchi (2019) focuses on the moral hazard incentives that arise following the issuance of contingent capital to increase the FI's level of risk, or to manipulate the market. He develops a structural credit risk model of a bank that issues short-term deposits, equity, and fixed- or floating-coupon contingent capital debt. Although issuing contingent capital can create a debt overhang problem and a moral hazard incentive for the FI to raise its asset risk, these problems are often less than if the bank issued a similar amount of subordinated debt. In general, incentive problems are mitigated when contract terms are such that CoCos' credit risk is minimized. The model predicts that CoCo credit spreads are higher when the capital conversion trigger is lower, the conversion write-down is greater and conversion awards a fixed, rather than variable, number of shares. Dual price trigger CoCos are more similar to nonconvertible subordinated debt.

Hilscher, Lazar and Raviv (2022) make the point that the inclusion of CoCos in banks' capital structure affects the sensitivity of equity-based compensation to risk and investigate how the design of CoCo bonds can reduce these risk-shifting incentives. A compensation package for executives which combines both stocks and CoCos can practically eliminate risk-shifting incentives, and can be implemented with a bank's pre-existing CoCo bonds.

Himmelberg and Tsyplakov (2020) propose a dynamic capital structure model to examine the optimal design and ex-ante incentive effects of issuing CoCos. The focus is on the issue of how conversion ratios dilute issuer's equity holders and thus generate incentives to preemptively raise equity capital to avoid triggering conversion. The model predicts that moderately dilutive conversion terms that prompt preemptive recapitalization result in fewer defaults, lower borrowing rates, and higher debt capacity when compared to less dilutive terms. However, highly dilutive conversion ratios that prompt too frequent recapitalizations do not always enhance efficiency because they create excessive adjustment costs. The alternative of writing down the CoCo principal at conversion without diluting equity holders creates perverse incentives to force conversion by destroying a portion of capital and generate windfall gains for equity holders.

4. Securitization

This section discusses papers that have as their underlying common theme the creation of financial securities by financial intermediaries. In this context, security design typically deals with the allocating cash flows generated by financial assets rather cash flows generated by firms. Specifically, it deals with an asset creation process called securitization, which involves the construction of pools of financial assets and the allocation of cash flows generated by these pools of assets. Securitization is the process through which financial intermediaries move individual financial assets or pools of assets off-balance sheet by selling them to a legal entity generically known as a special purpose vehicle (SPV).[8] The SPV finances the purchase of the assets with the proceeds from issuing securities of different seniority in capital markets. The securities that the SPV issues are called tranches, the most junior of which is called the equity tranche and which is typically retained by the SPV.

Securitization rests on a so-called originate-to-distribute banking model whereby the party issuing the newly created asset-backed securities (typically called issuer) is distinct from the party that originated the assets backing these newly created securities (typically called originator). The separation of origination and ownership has made it possible for originators to access liquidity by selling illiquid securities, such as loans, that would otherwise have had to remain on originating banks' balance sheet. However, it has weakened incentives to monitor and manage risks, making information frictions and the ensuing agency problems of moral hazard and adverse selection issues of first order importance.

In the context of securitization, moral hazard refers to a loan originator's ex-ante effort choice to screen and monitor loans, with the negative implication that loans which can be sold are not initially screened, or that securitized loans are not subsequently monitored. A number of empirical studies bring support to the existence of moral hazard problems related to lax screening and monitoring on behalf of originators. Keys, Mukherjee, Seru and Vig (2010) find that loans just above the FICO 620 threshold default at higher rates than loans just below. Since loans below the FICO threshold are harder to securitize, banks expect to hold more of them on balance sheet and expend more resources in their screening, which is reflected in the lower default rates. Elul (2016) analyzes the relationship between securitization and loan performance and finds that subprime securitized loans perform worse than equivalent portfolio loans. However, this study is unable to clearly separate the effect of lax screening from that of adverse selection.

Adverse selection refers to originators' ex-post incentives to subsequently sell low-quality loans to the SPV, with the unwanted implication that only low-quality loans are securitized. Adverse selection also affects SPVs that subsequently create and sell tranches to investors, as they typically have private information about the quality of the sold tranches. An, Deng and Gabriel (2011) demonstrate the existence of adverse selection in loan markets by comparing conduit lenders that have no flexibility to keep loans on the balance sheet, with portfolio lenders that choose which loans to sell for securitization. The paper rationalizes the empirical observation that loans originated by portfolio lenders are priced at a discount relative to conduit lenders, in terms of information asymmetries between loan originators and security buyers. Downing, Jaffee, and Wallace (2009) examine federally guaranteed mortgages, which have as main risk to investors the risk of prepayment, and find that pools retained by originators have lower prepayment propensities than pools that have been sold. Additionally, the yields on retained pools are higher than on the pools sold. Benmelech, Dlugosz and Ivashina (2012) argue that adverse selection issues are less severe in the case of corporate loan securitizations, because these securitized loans are fractions of

[8] Gorton and Metrick (2013) discuss the role played by financial innovation in the structure and design of the special purpose vehicle and the growth of securitization.

syndicated loans, and the mechanisms used to align incentives in a lending syndicate likely mitigate adverse selection in the choice of collateral.

Security design in the context of securitization refers to the issues of pooling and tranching. Whereas pooling refers to the choice of financial assets to pool and sell to the SPV, tranching deals with the choice of how to allocate the cash flows generated by the pool of assets to various categories of investors or, in other words, the capital structure of the SPV. Pooling or asset bundling involves tying cash flows together contractually with the express purpose of eliminating certain state-contingent payoff outcomes. Pooling can create liquidity by decreasing the amount of information relevant for valuing the asset-backed securities. This idea is illustrated by Glaeser and Kallal (1997), who study the relationship between pooling and market liquidity when information production by the seller of an asset-backed security is endogenous. Market liquidity can both rise and fall with the quantity of released information, as more information may increase information asymmetries and lemons-style market breakdowns. When the underlying assets are illiquid and affected by information asymmetries, pooling and reduced information disclosure are more likely to be optimal and result in improved liquidity.

Although pooling can be beneficial from a market liquidity perspective, it is not unambiguously optimal from asset sellers' perspective as it erodes any informational advantage that privately informed sellers might have. This effect is highlighted by DeMarzo (2005), who analyses the interaction between pooling and tranching. In addition to studying the issue of whether loans should be sold separately or pooled into a single portfolio, this paper also considers the SPV capital structure design issue. It is shown that intermediaries can enhance the returns to their private information by combining pooling and tranching. The forces at play when pooling are an information destruction effect, as informed issuers lose advantage of asset-specific private information when pooling, and a risk diversification effect through the creation of low-risk pools and associated securities that are less sensitive to the seller's private information. When an issuer has superior information about the value of its assets, it is better off selling assets separately rather than as a pool due to the information destruction effect of pooling. For uninformed sellers pooling is always preferred. However, the possibility of creating a security backed by these assets through tranching allows the issuer to exploit the risk diversification effect of pooling to create a low-risk and highly liquid security.

Given the trade-offs involved in pooling and tranching, the literature has looked into the forces that makes the combination of pooling and tranching optimal. Ortner and Schmalz (2019) study optimal security design when security issuers and market participants disagree about the characteristics of the underlying asset. They show that pooling and tranching assets can be preferable to selling securities backed by individual assets because belief disagreement between the issuer and investors can make pooling a best response, while belief disagreement among investors is something that the issuer can exploit through tranching. Thus, pooling and tranching can be complements when there are differences in beliefs, a result that does not obtain in the presence of asymmetric information alone.

The optimal pooling and tranching of cash flows has also been rationalized using departures from rational expectations. Noe, Rebello and Wang (2006) study the implications of adaptive learning for the evolution of security design. The evolutionary dominant security is one with large losses that occur with a small but positive probability, but which otherwise produces stable payoffs. In a rational expectations framework, optimal securities are pure state claims, meaning that each of the securities issued by the firm pays off only in a single state of the world and in any given state only one security is paying off. The model rationalizes the optimal bundling and splitting of cash flows based on a behavioral deviation from the rational expectations paradigm, namely the fact that investors learn how to price securities through experience.

Another departure from rational expectations is considered by Garmaise (2005), who studies the security design problem of a cash-constrained firm facing investors with diverse beliefs. A distinction is made between rational beliefs and rational expectations, in that under diverse beliefs agents are allowed to have beliefs that are diverse and yet rational in a specific sense. Investors may make incorrect forecasts at any point in time, but their forecasts will be correct on average. Under rational beliefs optimal securities maximize investor differences of opinion, while under rational expectations optimal designs minimize disagreements. The common practice of issuing multiple securities backed by a single asset is optimal under rational beliefs but not under rational expectations.

Tranching involves partitioning and selling the cash flows generated by underlying pools of assets to different classes of investors that differ with respect to seniority, resulting in a senior/subordinated financial structure design. The senior tranche can be thought of as being equivalent to debt, while the subordinated or junior tranche is conceptually similar to equity. Tranching enables decomposing asset cash flows into information insensitive component that is largely independent of a seller's private information, and an information sensitive component with cash flows that are dependent on the seller’s information. Thus, information asymmetries and in particular adverse selection arising from the potential informational advantage of the asset-backed security sellers are important frictions in relation to which optimal tranching has been studied.

Boot and Thakor (1993) rationalize the senior/subordinated security design in asset markets with adverse selection. They show that in an asymmetric information environment, the issuer's expected revenue is enhanced by selling multiple financial claims that partition its total asset cash flows, rather than selling a single claim, because such cash flow partitioning makes informed trade more profitable. When investors are asymmetrically informed about asset values, a value maximizing liquidation strategy may be to split cash flows into informationally insensitive and informationally sensitive securities. This is due to the presence of informed and uninformed investors in the market who choose to hold each of the respective categories.

Another paper that studies optimal tranching in relation to trading and the associated adverse selection issues is Friewald, Hennessy and Jankowitsch (2016). They consider in particular the complementarity between security design and strategic trading, in a context in which trading can be used to attenuate the costs of secondary market illiquidity. Uninformed investors are reluctant to sell due to adverse selection underpricing arising from the presence of an informed speculator who trades strategically in secondary markets. Uninformed investors demand primary market discounts equal to the sum of expected trading losses incurred by those who choose to sell plus expected carrying costs borne by those who choose to retain. The optimal tranche size is decreasing in cash flow information-sensitivity, but increasing in carrying costs. The optimal number of tranches is increasing in cash flow information-sensitivity and decreasing in carrying costs.

The optimality of tranching has also been rationalized in terms of non-exclusive markets. Asriyan and Vanasco (2020) study security design in a setup in which buyers post menus of contracts to screen a privately informed seller, and markets are non-exclusive in the sense that the seller cannot commit to accept contracts from only one buyer. They find that in equilibrium, cash flows are tranched into a senior tranche and a junior tranche. Whereas the seller of a high quality asset only issues the senior tranche, the seller of a low quality asset issues both tranches to distinct buyers, and the junior tranche is priced at a low valuation.

The importance of market structure has been studied by Glode, Opp and Sverchkov (2020), who take into account market structure and study optimal pooling in OTC markets. These are conceptualized as environments in which security issuers are facing counterparties endowed with market power. When the potential gains from trade are large, pooling assets may be suboptimal in the presence of market power, a result which is unlikely to be obtained in competitive markets. Pooling has the effect of reducing the elasticity of trade volume, thus exacerbating inefficient rationing associated with the exercise of market power.

Although securitization has been discussed as a factor that played an important role in the lead up to the crisis, Ozdenoren, Yuan, and Zhang (2021) point out that an optimally designed asset-backed security can eliminate multiple equilibria and improve welfare. The impact of asset-backed securities on the stability of market-based financial systems is studied in a dynamic setup in which borrowers obtain liquidity by issuing securities backed by current period payoffs, about which they are privately informed, as well as the resale price of a long-lived collateral asset. Asset prices can be self- fulfilling in the sense that higher asset prices allow borrowers to raise more funding, which makes the assets more valuable, leading to multiple equilibria. The optimal security design can be implemented as a liquid short-term repo contract backed by common collaterals. This amounts to the creation of liquid debt tranches backed by the resale price of collateral used by multiple borrower types.

DeMarzo, Frankel and Jin (2021) study securitization from the perspective of a portfolio liquidation game where the order in which assets in a portfolio are sold takes into account the impact of its sale on the value of the entire portfolio. They demonstrate the optimality of pooling securities and selling senior tranches or debt secured by the pool, with retention increasing in asset quality or informational asymmetry.

When originators are privately informed, the choice of how to split the cash flows as well as which tranche to retain has the effect of producing information. DeMarzo and Duffie (1999) study the optimal design of securities backed by specific assets by looking at the problem of a privately informed security seller which signals a high project value by retaining a portion of the issue. The security design problem involves a trade-off between the retention cost of holding cash flows not included in the security design, and the liquidity cost of including the cash flows and making the security design more sensitive to the issuer's private information. The illiquidity caused by the seller's private information can be mitigated through the issuers' tranche retention choice, which is effectively a way to signal its private information.

Tranching and retention choices can also be used to mitigate moral hazard issues. Fender and Mitchell (2009) study different contractual mechanisms that can be used to influence an originator's choice of costly effort to screen borrowers when the originator plans to securitize its loans. They focus in particular on retention mechanisms by considering an originator that can hold either a share of the portfolio called vertical slice, a mezzanine tranche or an equity tranche. If the probability of a downturn is likely and the equity tranche is likely to be depleted, equity tranche retention can be dominated by either a vertical slice or a mezzanine tranche. The retention mechanism may lead to low screening effort if the choice of how much and what form to retain is left up to the originator, which justifies government intervention. The role of regulation and market incentives in mitigating moral hazard has been explored empirically by Keys, Mukherjee, Seru and Vig (2009). They find that default rates were higher overall for loans originated by regulated banks than for less-regulated independent brokers, suggesting that regulatory oversight alone is not the solution. The paper findings point to a role for specific regulations requiring skin in the game for brokers in mitigating moral hazard.

The choice of which loans an originating bank sells to the SPV as well as the choice of which tranche the SPV retains, are effectively signals about the quality of the assets, with implications for regulation. Insofar as retention choices can be used to mitigate moral hazard issues, mandating appropriately designed retention schemes can be used as a regulatory tool. The relationship between originator effort, tranche retention and regulation has been studied by Chemla and Hennessy (2014), who consider optimal securitization and regulation in a model with moral hazard and asymmetric information about true asset values. In unregulated markets, high types can distinguish themselves from low types by retaining the smallest junior tranche, but pooling equilibria in which originators adopt identical structures are also possible. The paper also examines ex-ante effort incentives of originators who anticipate such marketing of securities under asymmetric information, and delivers predictions about optimal regulation promoting originator effort. Absent regulation, effort incentives are below first-best. In a separating regulation issuers choose from a menu of retentions and the size of the mandated retention is decreasing in price informativeness, whereas in a pooling regulation all issuers must retain the same claim.

Building on the idea that retention is used as a signal of quality, Daley, Green and Vanasco (2019) explore the implication of enhancing the availability of public information, such as credit ratings. The introduction of ratings has the effect of endogenously shifting the economy from a signaling equilibrium, in which banks inefficiently retain loans to signal quality, toward an originate-to-distribute equilibrium with zero retention and inefficiently low lending standards. When the reduction in costly retention is high enough to compensate for the origination of some negative net present value loans, ratings increase overall efficiency. The model is also used to analyze commonly proposed policies such as mandatory “skin in the game” regulation requiring that banks retain a fraction of all originated loans. The model predicts that skin in the game regulation leads to tighter lending standards and a reduction in credit supply since mandated retention exacerbates the use of retention as a signal of quality.

Rather than studying optimal security design from the perspective of the share of the underlying assets retained by the underwriter, Hartman-Glaser, Piskorski and Tchistyi (2012) focus on the timing of payments to the underwriter. They study optimal securitization with moral hazard in a dynamic setting in which a mortgage underwriter needs to exert costly hidden effort to screen borrowers and can sell loans to investors. Under the optimal contract the underwriter pools mortgages rather than selling each mortgage individually. Bundling mortgages allows investors to learn about the underwriter effort more quickly, an information enhancement effect caused by the fact that by observing the timing of a single default, the investors learn about the quality of the remaining mortgages. The optimal design of mortgage-backed securities is closely approximated by a so-called first loss piece contract which involves the underwriter retaining the junior tranche and receiving the proceeds from the sale of the senior tranche.

A number of studies also look into governance issues related to securitization, and specifically tackle the question of which tranche should have control rights. Riddiough (1997) studies the optimal design and governance of asset-backed securities in asset markets characterized by adverse selection. Asymmetric information of asset values and nonverifiability of liquidation motives give rise to lemons-related liquidation costs. Cash flow splitting allows the issuer to internalize some or all of the costs, with the implication that the senior/subordinated security design dominates whole loan sale. The paper also considers governance issues related to debt renegotiation and in particular the issue of which tranche should control liquidation and renegotiation. With pooled debt structures, it is the junior securityholder that should control the debt renegotiation process.

Riddiough and Zhu (2016) present theory and evidence on how governance structure affects security design. Incentives to resolve financial distress are affected by a tradeoff between moral hazard in costly effort provision and risk-shifting incentives, which depend on asset resale market conditions anticipated at the time of securities issuance. Effort provision is efficient with direct subordinate securityholder control over loan modification but there exist market conditions when concerns over risk-shifting costs predominate, so governance mechanisms that limit risk-shifting can be value enhancing. The model predictions are tested by looking at financially distressed mortgage loans in the private-label RMBS market in which a loan workout specialist has control over foreclosure-loan modification decisions. Evidence supports the relative efficiency of junior security control over the workout specialist. The value-enhancing properties of specific governance mechanisms are also empirically identified.

Although optimally designed securitization can bring about welfare improvements and the elimination of multiple equilibria, securitization has been pointed at as a key factor leading up to the crisis, and there is evidence that securitization depends on the risk of the underlying pool and more complex securities tend to have a worse performance. Chen, Liu, and Ryan (2008) examine the determinants of the size of the equity tranche retained by the sponsor and find that that banks retain more risk when the loans are more opaque and banks retain larger equity tranches when the pool is riskier based on public information. Park (2011) finds that subprime securitizations are more complicated than other securitizations, and credit enhancement mechanisms, including tranching, reflect the risk of the underlying portfolio. Furfine (2014) studies the relationship between complexity and loan performance in a large sample of commercial mortgage-backed securities. He documents a substantial increase in complexity between 2011 and 2007, and a worse performance for loans in more complex securitizations. Despite the fact that increased complexity of securitized products is associated with a worse performance, neither the price of a deal's securities nor the risk retention levels reflect that complexity correlates with lower quality. Thus, a byproduct of securitization is complexity, a subject that will be dealt with in the next section.

5. Complexity

The way financial intermediaries choose to design products has implications for investor decision making. This is especially salient in retail markets populated by unsophisticated investors, as supported by an increasing body of empirical evidence which shows that the law of one price is violated in retail financial markets, with significant price dispersion being observed even when products are homogeneous (see Carlin (2009) and references therein). Thus, complexity is an important concept in retail financial markets, which are typically conceptualized in the literature as markets populated by boundedly rational agents, that is, agents that are limited in their ability to fully and rationally process information. Brunnermeier and Oehmke (2009) point out three different ways in which boundedly rational investors can deal with complexity, namely by dividing up difficult problems into smaller sub-problems, by using models that capture simplified pictures of reality, or through standardization and commoditization of securities. Importantly, they point out that simply increasing the quantity of information disclosed to investors does not resolve complexity, since in the presence of bounded rationality it leads to information overload.

Carlin (2009) studies strategic price complexity in retail financial markets. In a non-cooperative oligopoly pricing model in which firms add complexity to their price structures, prices remain above marginal cost despite the large number of firms in the market, and may even rise as more firms enter. Adding complexity to prices tends to be a best response as competition increases, which in turn prevents some consumers from becoming knowledgeable about prices in the market, a phenomenon known as obfuscation. By making their prices more complex, producers of retail financial products gain market power and their ability to capture industry profits increases.

An important implication of security designers introducing complexity in their products is the fact that it obfuscates agents and limits information processing. Obfuscation is the process by which security designers are changing the number or nature of attributes of product offerings or complicating product information so as to slow learning and confuse consumers. Carlin and Manso (2010) study product complexity and obfuscation in retail financial markets. Specifically, the interaction between obfuscation and investor sophistication is studied under different learning behavior specifications within the investor population: there are experts who are always sophisticated, non-experts who become sophisticated transiently, and non-experts who remain unsophisticated. Sophistication is the outcome of a general learning process, and changing the specifications of the product offerings has the effect of "refreshing" investor sophistication to its initial level so that learning begins again. The paper provides a characterization of the optimal timing of obfuscation for financial institutions offering retail products, and shows that obfuscation decreases with competition among firms because the information rents gained by refreshing the population dissipate with more competition. Interestingly, they show that educational initiatives meant to facilitate learning by investors do not necessarily increase overall welfare, as they may induce providers to increase wasteful obfuscation, further disorienting investors.

Henderson and Pearson (2011) present empirical evidence which suggests that banks might shroud some aspects of the innovative securities they issue or introduce complexity so as to exploit uninformed investors. They find that the offering prices of 64 issues of popular retail structured equity products were on average 8% higher than these products' fair market values estimated using option pricing methods. Furthermore, the average expected return on these structured products was estimated to be slightly below zero, making it hard to rationalize their purchase by informed rational investors, given that the products did not provide tax, liquidity, or other benefits.

Obfuscation by financial intermediaries extends beyond the scope of security design and has also been shown to play a role in the context of bank portfolio holdings. Babus and Farboodi (2021) study a model in which banks can choose to strategically hold interconnected and opaque portfolios with a view to influence how investors can use their information, despite increasing the likelihood they are subject to financial crises. In equilibrium, banks' portfolios are excessively interconnected to obfuscate investor information, and portfolios are neither fully opaque nor fully transparent. Banks can create a degree of opacity that decreases welfare, and makes bank crises more likely.

Ghent, Torous and Valkanov (2017) provide empirical evidence of complexity obfuscating security quality in the context of the market for securitized products. They use data from the private label MBS market, and proxy for product complexity using six variables designed to measure the informational demands MBS deals impose on investors and the intricacies in structure across deals.

They establish that more complex securities perform worse, by documenting that securities in more complex deals default more and have lower realized returns. A one standard deviation increase in complexity represents an 18% increase in default on AAA securities. However, this is not accompanied by an increase in yields, indicating a failure on behalf of investors to perceive and price them as being riskier.

The relationship between complexity and product quality is theoretically explored by Asriyan, Foarta, and Vanasco (2020), who propose a model of product design with imperfect information, which can be used to understand how banks design financial products offered to retail investors, or how policymakers propose policies for approval by voters. They introduce a novel notion of complexity, which affects how costly it is for an agent to acquire information about product quality, and show that complexity is not necessarily a feature of low quality products. Higher product demand or lower competition among designers leads to more complex and lower quality products, but an increase in alignment between product designers and agents leads to more complex but better quality products.

While it might not be particularly surprising that FIs have an incentive to increase product complexity in order to increase profits, it is less clear what are the characteristics of the investor population that make product complexity an equilibrium outcome or, in other words, what are the investor preferences that complex security designs cater to. Complex securities have been shown to affect investment decisions by catering to retail investors' demand for safe assets, their yield appetite, to their loss aversion or pessimistic beliefs, or to the risk preferences of the main suppliers of capital.

Coval, Jurek and Stafford (2009) study how security design can be used to cater to investor demand for safe assets by looking at the ability of structured finance to repackage risks and create "safe" assets from otherwise risky collateral. Senior structured finance claims are designed to default only in extreme states of the world characterized by coordinated defaults, and credit ratings do not capture this systematic risks exposure. The paper highlights two features that make these products more dangerous than originally advertised. First, the issuance of structured products amplifies errors in evaluating the risk of the underlying securities, leading to extreme fragility of their ratings to modest imprecision in evaluating underlying risks. Second, structured products are highly exposed to systematic risks since the securitization process substitutes risks that are largely diversifiable for risks that are highly systematic.

Célérier and Vallée (2017) provide empirical evidence supporting the idea that financial complexity is a by-product of banks catering to yield-seeking investors. They study a large sample of retail structured products issued between 2002 and 2010 in Europe and measure complexity using the number of scenarios determining returns, the number of features or derivatives embedded in these products, as well as the length of the product description. They document that more complex and risker products advertise a higher possible return under their best-case scenario, so-called headline rate. Importantly, higher headline rate, more complex, and riskier products, appear more profitable to the banks distributing them.

Calvet, Célérier, Sodini and Vallée (2021) study how security design can mitigate behavioral biases and enhance economic well-being by increasing mean household portfolio returns. Specifically, by studying the introduction of capital guaranteed products in Sweden between 2002 and 2007, they are able to show that securities with non-linear payoff designs can foster household risk-taking. The introduction and adoption of these capital guaranteed products is associated with an increase in expected financial portfolio returns, especially for households with a low risk appetite ex-ante.

Grundy and Verwijmeren (2018) highlight the importance of the preferences of the suppliers of capital, i.e. security buyers, in security design by studying call provisions in convertible security design. The authors exploit the idea that convertible arbitrage, a strategy widely employed by hedge funds which involves combining the purchase of convertible debt with a short position in the stock of the same firm, is easier to implement when the convertible is not callable. The paper documents a decrease in the prevalence of callability features post 2005, which coupled with the fact that the market for new convertibles has since been dominated by hedge funds, highlights the role of security buyers in influencing security design. Overall, their results suggest that security design reflects the interplay between the preferences of security issuers and capital suppliers.

Given that investors fail to price the risks obfuscated through increased product complexity, regulating these markets is important. Carlin and Gervais (2012) study legal protection in retail financial markets. They show that when a retail financial institution outsources its advice services to an intermediary, regulations that enforce state-contingent legal rules are necessary in order to avoid market breakdowns. A system of penalties that depends on product characteristics and on the financial institutions relative ability to control quality is that which maximizes social welfare. Self-regulation does not achieve the same social efficiency in this setup in which the firm and its intermediary are jointly responsible for consumers experience with the products.

Célérier, Vallée and Liao (2021) investigate how security design affects equilibrium market outcomes. They study retail financial products embedding sales of put options and find that the development of markets for innovative securities can affect the supply and demand equilibrium for derivatives by channeling household demand through intermediaries hedging strategies. Results are consistent with the existence of segmented markets and speak to the equilibrium effects of a change in the set of participants for a given financial market, namely the retail demand for innovative securities. Security design does not only influence market outcomes but it influences market structure itself, and the next section deals with the two way relationship between security and market design.

6. Security and Market Design Interactions

This section covers studies at the intersection of security design and financial markets, which are closely related to the issue of innovation in financial markets. An important reason behind innovation is the desire to complete markets. In an incomplete market not all states of nature can be spanned, which means that agents are not able to move funds freely across time and space. A theory of optimal securities requires that markets should be incomplete. That is because the Modigliani and Miller result that capital structure is irrelevant when markets are complete implies that the form of securities issued is also irrelevant in these circumstances.

Allen and Gale (1988) study transaction costs as a reason for market incompleteness and show that profit motivated security design leads to an efficient allocation of resources. The securities that firms issue are endogenous, in that they are chosen optionally given the transaction costs of issuing securities, and the economy market structure is also endogenous. Market incompleteness gives rise to a clientele effect whereby different investors value assets differently at the margin. This implies that firms can increase their market value by issuing securities that take advantage of the different marginal valuations of the different clienteles. It also implies that arbitrage opportunities exits, which means equilibrium may not exist. The authors impose a no short sale constraint to limit arbitrage and show that in equilibrium debt and equity are not necessarily optimal. The optimal securities have an option like form in the sense that they involve allocating all the firm's output in a particular state to the security held by the group that values consumption the most in that state. Allen and Gale (1991) relax the no short sales constraint and show that when limited short sales are allowed, equilibrium is inefficient because the private benefits of innovation differ from the social benefits. Profit motivated security design does not lead to an efficient allocation of resources because short sellers are able to compete away part of the benefits of innovation.

Madan and Soubra (1991) study marketing costs as another reason for market incompleteness. The optimal solution employs portfolios of option-type products which display profit sharing in the higher profit states. In simple cases, this may involve the use of debt, equity, or warrant-type securities. More generally, in constructing optimal securities, the cash flow can first be split into options on the firm's value conditioned on sets of states. The extremal security design in Allen and Gale (1988), which never splits the firm's cash flow between securities in any state, is avoided because unlike issuing costs that depend only on the number of securities issued, the marketing costs studied here also depend on the security design structure as well as the issue price.

Market incompleteness creates incentives for agents to innovate, as value typically accrues to the innovators. Allen and Gale (1990) consider incentives to set up an options exchange and the efficiency of security design. The agent designing the derivative securities to be issued by the options exchange, which has a fixed setup cost, is the owner of the exchange. If the owner can capture all the surplus from opening the exchange, security design is efficient but in practice this is unlikely to be the case. Duffie and Jackson (1989) consider the optimal design of securities issued by futures exchanges. The objective of the exchanges in choosing the futures contracts to be traded is to maximize volume. The optimal contract for a monopolistic exchange is one that is perfectly correlated with the difference between the endowments on the long and the short sides of the market, each weighted by the risk tolerance of the other side of the market. In a monopolistic setting the contract design leads to a Pareto-optimal allocation of resources, but otherwise the allocation is not necessarily efficient.

Dow (1998) considers the costs and benefits of introducing a new security in a setup in which uninformed traders with hedging needs interact with risk-averse informed traders. The paper shows that opening a market in a new security may make everybody worse off. This is because liquidity in the old market is affected by the fact that risk-averse speculators can use hedging in the new market to eliminate the risk of their positions in the pre-existing market. The paper highlights the role of cross-market links between hedging and speculative demands, and how the availability of new hedging opportunities influences traders' strategies. Duffie and Rahi (1995) survey the literature on financial market innovation and security design and provide an encompassing framework for studying security design in incomplete financial markets, possibly with asymmetrically informed traders. They consider in particular the impact of financial innovation on risk-sharing and information aggregation.

Information frictions are an important force shaping security and market design interactions. Gorton and Pennacchi (1993) use them to rationalize the existence of seemingly redundant securities, namely composite securities with values that are functions of the cash flows or values of other assets. Although these securities might seem redundant since investors can cost1ess1y replicate them, their existence is justified if some investors possess inside information. Holding these composite securities allows uninformed investors with unexpected needs to trade to reduce their expected losses to informed insiders. Markets for the composite security and its component securities coexist when uninformed investors are differentiated into clienteles with respect to non-tradeable endowment shocks, and the size of each such clientele is small.

Marin and Rahi (2000) study security design in the context of a model in which the number and payoff of securities are endogenous, and which takes into account the fact that the efficacy of markets in aggregating and transmitting information depends on the financial structure and the number of tradeable assets. The theory of market incompleteness proposed in this paper is based on the information transmission role of prices and its adverse effect on risk-sharing in financial markets. Information revelation has two important effects that determine whether markets are optimally complete or incomplete. On the one hand, an adverse selection effect makes agents unwilling to trade risks when they have an informational disadvantage. On the other hand, there is a so-called Hirshleifer effect which implies that the revelation of information reduces risk-sharing opportunities because trading risks that have been resolved is impossible. When the adverse selection effect prevails, new securities are issued and prices reveal more information, but when the Hirshleifer effect is stronger, agents prefer an incomplete set of securities.

Frictions other than informational ones can play a role in security design, as highlighted by Shen, Yan, and Zhang (2014), who study the relationship between security design and collateral frictions. In the model of collateral-motivated financial innovation they propose, agents disagree about a portion of the cash flow from an asset, which motivates trading in the asset and possibly the introduction of derivatives. Importantly, agents need to back up their promises by collateral, and securities and collateral requirements are endogenous. The optimal security is a derivative that isolates the portion of the cash flow with disagreement, rather than the underlying asset. Markets remain incomplete even when investors introduce more securities than states.

Market segmentation is another important factor in relation to which financial innovation and security design have been studied. Biais, Hombert, and Weil (2021) propose a theory of market segmentation based on the imperfect pledgeability of security payoffs. The existence of incentive problems makes securities' payoffs imperfectly pledgeable and limits agents' ability to issue liabilities. As a result, markets are endogenously incomplete, leading to endogenous market segmentation. Market segmentation, in the sense of limited investor participation, is also studied by Rahi and Zigrand (2009), who consider strategic financial innovation in segmented markets. The asset structure is endogenous in the sense that it is the outcome of a security design game played by strategic arbitrageurs exploiting mispricings across different market segments. The equilibrium asset structure depends on depth and gains from trade, is generally neither complete nor socially optimal, and the degree of investor heterogeneity determines the degree of inefficiency.

Acharya and Bisin (2005) study financial innovations consisting of both the introduction of new assets and the integration of segmented markets, and characterize the optimal financial market structure. Uncoordinated innovations lead to efficient market structures whenever financial innovation consists of either the introduction of new assets into an economy without restricted participation or the relaxation of restricted participation constraints for an existing asset. In contrast, when the innovation consists of the introduction of new assets into economies with restricted participation, a decentralized innovation process does not necessarily result in optimal financial market structures. Innovations produce maximal welfare gains when the endowments of affected agents are negatively correlated. The structure of financial assets is optimal if all assets are designed to maximize risk-sharing. As a result, an optimal financial market structure is achieved when asset payoffs are correlated with the most important factors driving the dispersion of the agents' endowments.

The role played by market power in the relationship between security design and market structure is studied by Babus and Hachem (2021), who formalize the idea that the securities designed by financial intermediaries are not immune to the market structure in which trade occurs. The market structure is taken as given in the sense that an exchange is assumed to be introduced by the regulator to increase liquidity, and the focus is on characterizing the impact of adding access to the exchange on security design and investor welfare. Exchange trading alters security design to the detriment of investors. The security that intermediaries design after the introduction of the exchange is of lower quality because investors have zero price impact on the exchange and hence less influence on intermediary security design. Thus, investor market power is a powerful tool in disciplining the incentives of intermediaries in security design. Access to a centralized market increases the relative market power of financial intermediaries, enabling them to issue riskier securities than they otherwise would.

Babus and Hachem (2022) consider the joint determination of market structure and security design. The securities issued and structure of the market are endogenously determined and financial intermediaries issue securities taking into account the markets in which the securities will be traded. Investors act strategically when markets form in the sense that they understand the fact that their choice of which market to participate in affects the design of the security they will be trading. They are also strategic when they trade, in that each investor understands the impact of her trade on the price of the security. The model predicts that intermediaries will create increasingly riskier securities when facing deeper, more concentrated markets because financial intermediaries have more market power relative to investors. Financial intermediaries have an incentive to issue equity when markets are deeper and debt when markets are thinner, which explains why standardized securities are frequently traded in decentralized markets. Investors choose to trade in thinner, more fragmented markets to obtain safer securities.

Rostek and Yoon (2021) study the role of market structure and imperfect competition for the design of synthetic products, and show that decentralized trading motivates financial innovation, making derivatives non-redundant. The notion of decentralization used here is that demands are not contingent and most assets clear independently rather than jointly. The paper takes into account that most markets are dominated by large traders whose behavior impacts prices, so dealing with price impact represents a primary motive for creating an alternative trading venue or introducing a new financial product. In markets with large traders, derivatives alter the price impact for the underlying assets, and improve risk-sharing and diversification when suitably designed. The efficient set of securities allows trading all fundamental risks but generally forgoes hedging all contingencies in response to price impact. However, when traders have no price impact, efficiency entails that all contingencies be hedged.

The question of how securities and markets can be designed to mitigate market imperfections is studied by Biais and Mariotti (2005). The focus is on the role of security and market design in enhancing market liquidity and the efficiency of securities issuance and trading. Given an arbitrary security, the optimal trading mechanism involves issuers with low cash flows selling their entire security holdings and issuers with high cash flows being excluded from trade. An optimally designed security can help issuers avoid exclusion. The optimal security is debt, because its low information sensitivity mitigates adverse selection, and it also mitigates strategic behavior on behalf of monopolistic liquidity suppliers by pooling all issuers with high cash flows.

The emergence of market structure and intermediation is studied by Farboodi, Jarosch and Shimer (2022), who consider a setup in which OTC market participants make a costly investment governing how often they are in bilateral contact with others. A rich market structure emerges both in equilibrium and in an optimal allocation. If market participants have heterogeneous contact rates, intermediation arises naturally and participants who are more often in contact with others act as intermediaries.

7. Fintech

Fintech refers to a wide range of applications of technology towards the provision of financial services. The major technological innovation at the core of fintech is the distributed ledger technology (DLT). DLT is a database architecture which enables the keeping and sharing of records in a distributed and decentralized way, while ensuring its integrity through the use of consensus-based validation protocols and cryptographic signatures. The key feature of DLT is decentralization, which means that the database is independently constructed and held by each participant, also known as a node, in a large network. Unlike centralized ledgers, distributed ledgers have no central data store or administration functionality. The record keeping process that makes possible decentralization is one which involves every node processing every transaction, coming to its own conclusions about the true status of the ledger and voting on those conclusions to make sure the majority agree with the conclusions. Once there is consensus, the distributed ledger is updated, and all nodes maintain their own identical copy of the ledger.

Allen, Gu and Jagtiani (2021) provide a comprehensive survey of the wide range of applications of DLT in finance, which include credit scoring, marketplace and peer-to-peer lending, digital payments, cryptocurrencies and central bank digital currencies, investments and trading, cybersecurity and regulation, and many others. The applications most pertinent to our review are those related to corporate financing, corporate governance, blockchain governance and consensus mechanism design, tokenization or securities digitization, trading and financial market design.

The most widely known type of distributed ledger is the so-called blockchain underlying the popular cryptocurrency Bitcoin, which organizes data into blocks that are chained together using cryptographic signatures and then broadcasts them to the nodes in the network. Although DLT and blockchain are mainly known in relation to their representation of cryptocurrencies, securities other than digital currencies can be represented on the blockchain, a process known as tokenization. Security tokenization refers to the digital representation of traditional financial assets, physical assets or utility on a distributed ledger. According to the Securities and Exchange Commission tokens can be classified into three categories: cryptocurrency tokens, security tokens and utility tokens. Cryptocurrency tokens are a means of exchange and a store of value similar in spirit to fiat centralized currency; security tokens represent a conventional financial security that is recorded and exchanged on a distributed ledger; utility tokens give the holder the right to access a product or services on a platform.

Applications to corporate finance mainly tackle the issue of capital structure and the optimality of alternative forms of financing that have been made possible by the technology, such as initial coin offerings (ICOs).[9] In an ICO a firm raises funds by issuing digital coins or tokens, to finance the

[9] Allen (2021) reviews the development of ICOs in recent years as well as the recent studies on ICOs and discusses the advantages of ICOs compared with traditional IPOs.

development of a platform offering a new product or virtual currency. The tokens purchased in an ICO give holders various rights, most frequently the right to use the platform services that are being developed, as well as ownership rights similar to those observed in traditional equity markets. The use of digital tokens for launching peer-to-peer platforms is rationalized by Li and Mann (2018). Insofar as the blockchain technology allows to transparently distribute tokens before the platform begins operation, a token sale overcomes later coordination failures between transaction counterparties during the platform operation. That is because the costly and observable action of token acquisition credibly communicates the intent to participate on the platform.

Typically the token that is offered for sale in the ICO comes with the promise that it will be the only medium of exchange for the platform's future products or services. So these tokens serve both as initial financing for the platform and as a transaction medium for the members of the platform. They can also be exchanged for other cryptocurrencies or fiat currency in secondary markets, so a notable feature characterizing these securities is that the buyers can be platform users as well as speculators. Sockin and Xiong (2020) examine how the interaction between users and speculators affects platform fragility. They show that while user optimism mitigates fragility by increasing user participation, speculator sentiment exacerbates it by crowding users out. Speculator participation also means that the due diligence process can be crowdsourced beyond the potential early adopters, as favorable assessments of the venture can be leveraged with speculative token purchases. This idea is explored by Bakos and Halaburda (2019), who consider the problem of funding new ventures with digital tokens, focusing on tradability and broader crowdsourcing of due diligence as the key characteristics of the tokens studied. They compare funding via digital tokens with funding from traditional financing sources like venture capital or pre-sale crowdfunding with non-tradable rewards. Their model predicts that tradable digital tokens are more attractive when there is higher uncertainty about market demand, and in such cases crowdsourcing due diligence benefits from the information contained in the private valuations of the early potential adopters. Token tradability leverages that private information and increases the amount that can be financed, and although it comes at the cost of a lower digital token price and lower total profit for the entrepreneur, it may still be preferable to the alternatives considered.

A number of studies compare traditional equity financing via Initial Public Offerings (IPOs) with token-based financing via Initial Coin Offerings (ICOs). The optimal form of financing typically depends on the frictions considered and the characteristics of the venture to be funded. Gryglewicz, Mayer and Morellec (2020) study the conditions under which a firm seeking to raise outside funds to finance platform development prefers token financing to equity financing, as well as the issue of optimal token design in the presence of agency conflicts between platform developers and investors. The model considers tokens with utility features, which serve as the transaction medium on the platform or offer access to the firm's services, and tokens with security features, which grant cash flow or dividend rights. An ICO is the optimal mode of financing if the platform derives value from facilitating transactions rather than from generating cash flows. Equity financing is preferred to token financing if the platform expects strong cash flows, has large financing needs, or faces severe agency conflicts. The optimal token security features granting cash flow rights and the optimal level of token retention decrease in the extent of financing needs and agency conflicts.

Chod and Lyandres (2020) also compare token financing with traditional equity financing, focusing on agency problems associated with the two methods as well as risk-sharing between platform developers and investors. The key characteristic of the tokens studied in this model is that they represent a claim on the platform's output. Tokens can be a superior form of financing for ventures providing information goods or services, for those where entrepreneurial effort is important and those with relatively low payoff volatility. Tokens can also be superior in signaling the quality of the venture to investors.

Comparing traditional equity with token financing is also relevant from the perspective of aligning the incentives of platform developers and investors. Garratt and Oordt (2019) take a corporate governance perspective and study how financing a start-up through an ICO changes the incentives of a platform developer relative to debt and venture capital financing. Depending on the venture characteristics, an ICO can be the only form of financing that induces optimal effort and hence maximizes the net present value of the start-up, and there are projects that should not take place at all unless they can be financed through an ICO.

Tokenization enables the use of smart contracts as the basis for the transference. Smart contracts are contingent contracts which can automatically self-adjust and execute pre-determined actions based on incoming data. Specifically, they are computerized protocols which allow for terms contingent on decentralized consensus and which are tamperproof and self-enforcing via automated execution. Smart contracts are encoded to assure one party that its counterparty will fulfill the promise with certainty and can, as a consequence, eliminate in an automated and conflict-free way some contracting frictions like the need for costly verification, enforcement or the risk of renegotiation. By enabling commitment to predetermined rules, smart contracts and the blockchain technology can address dynamic inconsistency problems and, as demonstrated by Cong, Li and Wang (2021), can alleviate underinvestment problems caused by conflicts of interests between platform owners and users. In the model they develop tokens serve as a means of payments among platform users and are issued to finance investment in platform productivity. In equilibrium, when the ratio of token supply to platform productivity is high the platform cuts back investment and refrains from payouts. So a conflict of interests arises because to reduce token supply and boost token price, the platform may find it optimal to buy back tokens and doing so requires costly external funds, which ultimately causes underinvestment.

Tinn (2017) considers the use of smart contracts in a firm financing setup by studying the problem of an entrepreneur seeking to secure external financing through the issuance of smart contracts that enable pre-commitment to contractual terms. She considers a dynamic moral hazard environment where there is no information asymmetry at the time of contracting but there is learning from the realized sales data, which can change the borrower's effort incentives ex-post. When enforcement is frictionless and cash flows are verifiable, blockchain technology facilitates faster learning and more frequent effort decisions, which in turn changes the type of financing contracts that are the most efficient or even makes traditional debt and equity contracts more costly. The optimal financing contract is a dynamically adjusting profit-sharing rule that depends on incoming sales revenues. Using a self-adjusting optimal contract instead of simple equity is more beneficial if the realized sales are more informative about the target market. In the very special case where sales are independently and identically distributed (rather than stochastically affiliated) and effort cost is constant, a simple equity contract is the optimal contract. Debt contracts are suboptimal not only compared to the optimal contract but also compared to equity.

Notwithstanding the benefits brought about and the frictions overcome by this form of financing, it is also affected by problems such as limited commitment in new token issuance, which can render it inferior relative to traditional equity. Catalini and Gans (2019) study the problem of an entrepreneur seeking to finance a start-up using traditional equity, or using crypto-tokens when the issuer commits to only accept those tokens as payment for their products. The initial funds raised are maximized by setting to zero the growth in tokens supply over time, and the value of the tokens depends on a single period of demand. Given the lack of commitment in monetary policy, the cost of using tokens to fund the start-up is inflexibility in future capital raises and the ability to raise funds is more limited than in traditional equity finance. Issuing equity is superior to issuing tokens because it can monetize the future equity return stream and so raise more money.

Malinova and Park (2018) also demonstrate that equity is better than a simple token structure. However, an optimally designed token contract yields the same payoff as equity. Tokens that grant rights to future economic output are economically inferior to equity and lead to over- or under-production relative to the production quantity that maximizes the venture's aggregate profits. The optimal contract combines an output presale and an incremental revenue-sharing agreement, which means that in addition to selling a set of initial tokens, the issuer also commits to offer investors a share in the revenues from the tokens issued after the production decision.

A number of studies at the intersection of fintech and corporate governance examine the blockchain innovation from the perspective of its interaction with existing corporate governance structures as well as the new governance possibilities that it brings about. Yermack (2017) overviews the impact of blockchain on corporate governance and argues that, in addition to resulting in lower cost and more accurate record keeping, a blockchain could bring greater liquidity and improve transparency of ownership. In light of the consensus mechanism that replaces the needs for trust, the blockchain can be viewed as a new and efficient governance mechanism for companies and markets. This technology has opened up the possibility that organizations can be regulated by autonomous code. Specifically, the fact that various decision processes and rules can be implemented in the computer code has brought about the emergence of new structures such as decentralized autonomous organizations (DOAs). A DOA is an entity where the rules of governance are represented by a collection of smart contracts and executed when required, so humans or other entities interact via a computer protocol. As noted by Karjalainen (2020), governance through computer codes has the advantage of being unambiguous, deterministic and transparent, not leaving room for interpretation and making possible the enforcement of network rules at a minimum expense. However, the big problem is that any formal rules will be incomplete.

On the other hand, the issue of governance of the blockchain itself is an important one, and under some but not all designs it is a function of security holdings. Karjalainen (2020) studies governance as applied to the design and maintenance of decentralized network protocols. The allocation of decision or governance power to the network users depends on the consensus mechanism design and, in some cases, on their token holdings. The issue of blockchain governance is closely related to the question of who has the right to write on the blockchain, and three main types of blockchain can be distinguished based on who the record-keepers are: private, permissioned, and public. In the private blockchain control rights are given to one entity with authority, identified as the sponsor or gatekeeper, which takes complete control over what is written on the ledger.[10] In a permissioned blockchain the write privilege is granted to a consortium of entities which govern the policies of the blockchain and take control of verifying and propagating transactions. In the public blockchain the right to write on the ledger is completely

[10] The sponsor can also restrict entry to into a market, access monopolistic user fees, edit incoming data or limit users' access to market data.

unrestricted and writers are allowed to be anonymous, so there needs to be an efficient, fair, and real-time mechanism to ensure that all participants agree on a consensus on the status of the ledger. This is achieved through a consensus mechanism, which is a method for validating entries into a distributed database and keeping the database secure. Well known types of consensus mechanism algorithms include proof of work (PoW) and proof of stake (PoS). In PoW, anonymous record-keepers known as miners effectively vote on the true state of a chain of blocks by extending that chain, which in turn requires an expenditure of computational power.[11] In the PoS blockchain, on the other hand, voting power is based on the stake that each node or participants has in the network, which is captured by the number of tokens held in each account. So, in a PoW system, any agent may vote by paying a computational cost to solve a difficult but meaningless cryptographic problem, and in a PoS system, voting power is given to token holders.

In the PoS blockchain there exists a relationship between security holdings and control rights. Saleh (2020) provides a first formal economic model of the PoS blockchain protocol and studies the conditions under which consensus is generated. He establishes two design choices that PoS developers may employ to generate consensus: a minimum stake threshold for validators which restricts access to update the ledger to sufficiently large stakeholders, and a modest block reward schedule which requires keeping small the block rewards offered to validators for updating the ledger.

Abadi and Brunnermeier (2019) study consensus mechanism designs when agents are permitted to act and collude in arbitrary ways, and compare the cost and incentive schemes required to secure both centralized and decentralized record-keeping systems. Whereas in a centralized ledger incentives for honest reporting are ensured by the loss of rents that would result if the users of the system abandon it upon discovering fraudulent activity, in the PoW decentralized ledger, record-keeping integrity is ensured by the computational costs needed to write on the ledger, which render dishonesty unprofitable from an ex-ante perspective. In a PoS system, on the other hand, there are external punishments associated with the potential break down of trust and the ensuing dissolution of a social network in which agents have mutually beneficial relationships. They prove a blockchain trilemma whereby no digital ledger can simultaneously satisfy the three properties of self-sufficiency (absence of external punishments for dishonest behavior), no rent extraction, and resource efficiency (absence of resource costs to write on ledger) in order to achieve consensus.

The implications of the DLT for trading and financial markets are best understood in light of the fact that financial securities can be digitally represented, which in turn makes possible the use of smart contracts as the basis for transference. This has created the expectation that DLT will reduce or even eliminate inefficiencies and frictions that currently exist in relation to storing, recording, transferring, and exchanging digital assets in financial markets.[12] Lee, Martin and Townsend (2021a) analyze the impact on market efficiency of a token system which allows for the programming of assets and resolves settlement risk. The idea behind asset programmability in this context is that the parties would jointly write a program that governs the change of ownership of assets. The paper takes as given a token system that resolves settlement risk, and considers how

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[11] Biais, Bisiere, Bouvard and Casamatta (2019) study the PoW blockchain protocol from the perspective of a coordination game with multiple equilibria. Ma, Gans and Tourky (2019) provide technical foundation for any economic analysis of PoW protocol, and center their analysis on resource usage, competition and market structure regulation.

[12] Mills et al. (2017) provide a policy discussion on the use of DLT in payments, clearing and settlement, while Benos, Garratt, and Gurrola-Perez (2017) focus on DLT-based security settlement.

trade is endogenously determined. While tokenization solves settlement uncertainty arising from limited commitment, it creates a hold-up problem and even the breakdown of trade because intermediaries must purchase assets in advance to facilitate a transaction (trade execution and settlement are not separate). This trade-off is especially severe in markets that depend on intermediaries.

Rather than assuming a market based on token systems that resolves settlement risk, Lee, Martin and Townsend (2021b) study the problem of designing zero settlement risk token systems, taking as given a fixed set of trades. It is shown that it is not true in general that asset programmability resolves settlement risk. The problem of limiting settlement risk boils down to imposing restrictions on traders' actions set to limit their abilities to act on ex-post incentives to deviate. The paper seeks to understand whether there exists a system that has zero settlement risk in the sense that agents cannot renege on settlement contractual obligations, and is information leakage proof in the sense that the information revealed to the bookkeepers should be in the information set of other traders. The legacy system is information leakage proof but is subject to settlement risk. A token system satisfies both features if and only if the protocol is such that it requires immediate settlement and is restricted to non-contingent transfers that are to occur unconditionally, since contingent programs are open to the possibility of information leakage.

Another issue that becomes particularly relevant when it comes to pushing for real-world applications of the blockchain technology is privacy. This point is made by Cong and He (2018), who focus on studying the issue of how ledger transparency leads to a greater scope for collusion between users of the platform. Although the technology enlarges the contracting space through smart contracts, decentralized consensus entails distributing all transaction information, which in turn affects competition.

Transparency related issues are also studied by Malinova and Park (2017), who explore different blockchain market designs in the context of a theoretical model of intermediated and peer-to-peer trading. By allowing to create a decentralized digital ledger of transactions and to share it among a network of computers, the blockchain technology offers investors new options for managing the degree of transparency of their holdings and their trading intentions. The paper studies how the implementation design of two critical features, namely the mapping between identifiers and end-investors on the one hand, and the degree of transparency of the ledger on the other hand, affects investor trading behavior, trading costs, and investor welfare. Despite the fact that by revealing their identities traders are exposed to the risk of front-running, the most transparent setting yields the highest investor welfare. In the absence of full transparency, the net aggregate welfare is weakly higher if investors are allowed to split their holdings among many identifiers.

Recently, several market initiatives have begun exploring the application of DLT to the fast growing field of sustainable and climate finance. The Bank for International Settlements (BIS) Innovation Hub and the Hong Kong Monetary Authority (HKMA) have introduced two prototype digital platforms for the tokenization of green bonds, which aim to streamline the green bond issuance process, and make it easier to track projects' positive environmental impact. The initiatives aim to enable small denomination investments into safe government bonds which fund the development of green projects, and to allow investors to monitor through an app not only accrued interest, but also to track in real time how much clean energy is being generated and the consequent reduction in CO_2 emissions linked to the investment. Thus, the objective is to reduce the uncertainty about whether the bond issuer is delivering the positive green impact it committed to at issuance, and also to create liquid and transparent secondary markets for retail investors. The prototypes employ permissioned distributed ledger[13] and public permissionless blockchain infrastructure[14], and streamline processes which include origination, subscription, settlement and secondary trading.

However, there have also been more questionable applications of DLT to the field of climate finance, both of which represent rapidly evolving fields the regulation of which is still underway. This is evidenced by the emergence of so-called digitized carbon offsets, which are tokens that can be used to offset emissions or converted into a new cryptocurrency, Klima.[15] While supporters point to uniformization as an advantage, concerns exist that crypto traders have scoured the carbon market for older, cheaper offsets to buy and tokenise. Specifically, some credits that were generated pre-2010, have raised questions as to whether they genuinely represent the carbon savings they promised, opening the door for laundering poor quality offsets.

8. Sustainable Finance

The issue of how to optimally design contracts that finance projects delivering non-pecuniary sustainability-related benefits is one that has grown in importance considerably in recent years and one that is still poorly understood. Contracting in the presence of non-pecuniary benefits is not a new subject (Aghion and Bolton, 1992). However, while the early literature typically considers contracting as a means to prevent agents from extracting private benefits, in the context of the emerging field of sustainable finance the focus has shifted to contracting as a means to incentivize the provision of public benefits, which is a notoriously difficult issue.

Traditionally, the funding of projects yielding public benefits has been pursued by public entities and has employed public money. Funding has been provided in the form of either grants or government commissioned block contracts. Recently though, there has been a shift in investor preferences and ideology regarding private firms' responsibility to contribute to the public good, which has brought about the rise of so-called impact investing. The idea behind impact investing is the joint pursuit of financial returns as well as the intent to contribute to measurable positive social and/or environmental benefits. Hybrid solutions for funding projects yielding public benefits have emerged, which involve a mix of public and private funding and which have been implemented through Social Impact Bonds (SIBs) or Pay-for-Success bonds. Most recently, purely private funding solutions, which include securities such as green bonds and loans as well as sustainability-linked loans and bonds, have seen an exponential growth and now make up most of the sustainable finance market.

Social Impact Bonds (SIBs) are the financial securities most widely employed to fund the provision of positive social impacts. The parties involved in a typical SIB are a commissioner (which is typically a public administration) that contracts the provision of a social service of interest to an external service provider (which is typically a non-profit organization) that implements the commissioned project and delivers the social service. Importantly, funding is provided by private investors, and the public administration with an interest in providing the service acts as an intermediary. Thus, this is a contract between a public administrator that cares to provide a social service but will contract it out to an external service provider, and private

[13] https://www.bis.org/publ/othp43_report3.pdf
[14] https://www.bis.org/publ/othp43_report2.pdf
[15] https://www.ft.com/content/ed76933e-43ed-4e72-ac19-ef47a731a595?desktop=true&segmentId=7c8f09b9-9b61-4fbb-9430-9208a9e233c8

investors that provide upfront funding for interventions to improve specific social outcomes. By employing private capital market funding to solve social problems, SIBs represent an alternative to government funding for social welfare services. Instead of public administrations paying non-profit organizations to deliver a social service of interest, private investors provide the funding and are repaid later the principal and potentially a profit by the government if the service meets agreed-on performance benchmarks. So these contracts are designed to incentivize investors to provide funding for projects addressing social challenges by providing them with a return which increases with the social performance of the project.

Rangan and Chase (2015) describe the typical funding structure of an SIB, which involves funders falling in three categories: senior lenders, junior lenders and venture philanthropists, which have a decreasing degree of interest in financial returns. Senior lenders are largely profit motivated investors that will be repaid first. Junior lenders are mainly what can be called impact investors in that they care about the impact of the project as well as financial returns. Philanthropic investors have the weakest profit motive, provide services like loan guarantees and will be the last to see their principal repaid. Much of the risk is absorbed by the second and third categories whose motivations differ from those of profit-seeking investors. An important role in the design of SIB funding schemes is played by the public administration that cares to provide the service, which acts as mediator, as well as philanthropic funding, which protect the first two categories and is essentially a substitute to government funding.

Roth (2021) examines the role of impact investors relative to pure philanthropists or donors in supporting social entrepreneurship. He studies the optimal mode of financing for a firm that is socially motivated, in that it values social goals in addition to profits, when the financing options are simple grants and investments. Unlike grants, which can be thought of as a full subsidy or donation, the investment is a partial subsidy which also involves taking a claim on the firm's assets and extracting profits from it. Financiers place intrinsic value on the firm's social output so grants are an optimal form of financing because the interests of the firm and of the financiers are aligned. Grants achieve the first-best outcome for organizations that are not sustainable under the grant financing regime, where organizational sustainability is defined as the level of sustainability past which an organization is a net distributor to it financiers rather than a net receiver. Defined as such, it is organizational sustainability that leads to impact investing, rather than the other way around.

A number of studies compare SIBs with alternative funding arrangements and explore the conditions under which SIBs add value to the involved stakeholders. Wong, Ortmann, Motta and Zhang (2016) compare SIBs with the types of contracts that public administrators typically offer non-profits, namely input-based (IB) and performance-based (PB) contracts. IBs contain a piece-rate mechanism that involves a wage and a piece-rate that is paid for every unit of effort the non-profit exerts on a task. PBs contain a non-binding bonus mechanism which involves a wage and the promise of a bonus paid once the public administrator observes the non-profit's chosen effort levels, but the payment is assumed not to be enforceable. SIBs contain a mechanism that, due to the presence of an investor, is assumed to offer full enforceability, which implies that investors can write contracts based on the non-profit's performance and thus tie the financial returns of investors to the success of social programs. SIBs can outperform PB contracts because of their perfect enforceability but this enforceability means that public administrators lose control over the payoff to investors. From the public administrator's viewpoint, IBs are preferred to PBs but are dominated by SIBs. Note that an important assumption is that the presence of investors makes the contingent payments fully enforceable.

The idea that investors play an important role in a typical SIB funding structure is also studies by Pauly and Swanson (2017), who look at the problem of a non-profit service provider that seeks to obtain financing either through a combination of donations and traditional debt, or jointly with altruistic investors through an SIB contract with the government. The government is willing to finance a performance-contingent social service program, and the needed capital is provided by a large number of private investors upfront, some of which are altruistic in that they have both financial and social incentives. The success of the program depends upon the involvement of altruistic SIB investors in the organization of the service provision. SIBs will lead to greater program success if investors' effort responds to incentives and can positively influence the social outcomes, either directly through effort exerted in production, or indirectly through effort devoted to screening.

Tortorice, Bloom, Kirby and Regan (2022) examine the extent to which SIBs can finance positive net present value projects that traditional debt finance cannot. While debt constrains the government's payments to be constant across states of the world, SIBs allow the payments to be conditional on the benefits the government receives in each state of the world. When governments are pessimistic relative to the private sector about the probability of success of an intervention, SIBs expand the set of implementable projects. Similarly, SIBs can finance positive net present value projects that debt finance cannot if the government is particularly averse to states of the world in which project benefits cannot offset the project costs.

SIBs have contingent payoffs in the sense that the financial performance of these instruments depends on the performance of the underlying project funded by the bond, in a way that rewards investors for financing the social cause. As emphasized by Rangan and Chase (2015), these contracts are most appropriate when non-profits are able to effectively deliver and measure social impact and to translate this impact into financial benefits or cost savings. In other words, measurability and quantification of social outcomes is an issue of great importance, as impact has to be quantifiable and to result in clear and significant cost savings. This is likely why SIBs have narrow thematic and geographic scopes, typically focusing on reducing employment, recidivism or improving social care in a clearly defined geographical area such as a city or region.

In recent years, global warming has changed the scope of the environmental and social challenges faced by society, and has brought about a change in investor preferences that have traditionally been concerned with the pursuit of financial returns alone, to a new regime in which they also value non-pecuniary public benefits and the reduction of negative externalities. This change in preferences has marked the emergence of a purely private market for funding projects aimed at yielding public benefits.[16] Worth noting is that both the purely public as well as the hybrid approach to financing projects yielding public benefits rely on the public entity having an interest in the cause and being involved in facilitating the financing. By contrast, the private solution is predicated on investors actually caring rather than having to be incentivized to finance the provision of non-pecuniary outcomes.

The change in investor preferences is evidence by a sharp increase in the market for sustainable finance. The capital deployed to addressing environmental, social and sustainability challenges

[16] Corporate Social Responsibility (CSR) is also a private solution tackling societal challenges but it is more similar to a donation rather than an investment. Besley and Ghatak (2007) compare CSR with government provision and charitable provision, discussing when CSR by private for-profit firms could have a comparative advantage in dealing with public goods provision.

has increased from an annual volume of $11 million in 2007, to $1,268 million in 2021, reaching a total cumulative volume of approximately $3 billion in the first quarter of 2022. The market has also seen a proliferation of financial products. Green loans and bonds, social bonds and sustainability bonds pledge the proceeds to financing projects that deliver environmental, social or sustainability benefits, respectively.[17] Another class of securities, comprising sustainability-linked loans and bonds, does not pledge proceeds to specific projects, but instead involves commitment to outcomes by making the cost of debt contingent on the issuer achieving pre-set sustainability targets. This class of debt contracts usually embeds a two-way pricing structure whereby if the borrower meets its sustainability target then the rate of return on the security decreases, but if it fails to meet its targets then the interest rate increases. Thus, the return to investors depends negatively on sustainability performance, unlike SIBs which have a financial return that depends positively on the performance of the project funded.

The increased interest of investors in sustainability-related issues has been attributed to the fact that these will presumably affect financial returns in the long term. While the hybrid funding solution implemented with SIBs is specifically designed to offer investors better returns by doing good, the basic assumption underlying the purely private funding solution is that the failure to prioritize sustainability will have negative economic consequences. So an important issue when considering financing projects that involve monetary and non-monetary outcomes concerns the relation between these two components, as it is not clear whether they are positively correlated or one comes at the expense of the other. In theory, when investors care about both monetary and non-monetary outcomes, they are willing to forgo financial returns by paying a risk premium, typically called a green premium, for the non-monetary benefit (Pástor, Stambaugh and Taylor, 2021). However, the evidence on the existence of a green premium is mixed.[18]

Investments that have the potential to provide monetary as well as non-monetary benefits are affected by an agency conflict regarding which output to emphasize. Hart and Zingales (2017) prescribe corporate governance and shareholder activism as a means to balance profitability against social harm. Funding structures that involve a mix of financially and public-good oriented investors represent an implicit governance mechanism, and are an alternative to direct governance. This idea is explored by Chowdhry, Davies and Waters (2019), who propose a model in which firms that cannot commit to social goals are jointly financed by profit- and socially-motivated investors, and thus face a trade-off regarding which output to emphasize. Insofar as holdings of financial claims by socially-motivated investors counterbalance tendencies to overemphasize profits, investments by this class of investors improve social outcomes if they hold a sufficiently large financial claim. The mass of socially-motivated investors plays an important role in achieving impact by creating incentives for firms to undertake social projects. Financial contracting can be used to aligns incentives among these heterogeneously motivated investor groups if contracts are made contingent on realized social output. Specifically, incentive alignment

[17] In line with the ICMA standards governing the issuance of securities on the sustainable finance market, the term sustainability is broader and encompasses environmental as well as social and potentially governance related issues.
[18] Whereas some studies report evidence in support of the existence of a green premium (Ehlers and Packer (2017), Kapraun, Latino, Scheins and Schlag (2021), Baker, Bergstresser, Serafeim and Wurgler (2018)), studies using tighter methodological approaches do not find any such evidence (Larcker and Watts (2020), Flammer (2020)). A systematic literature review by MacAskill, Roca, Liu, Stewart and Sahin (2021) confirms the existence of a green premium within 56% of primary and 70% of secondary market studies, particularly for those green bonds that are government issued, investment grade, and that follow defined green bond governance and reporting procedures.

is best achieved when the most profit-motivated agent holds a pay-for-success contract that provides a larger payment when social goals are achieved.

Oehmke and Opp (2020) derive the conditions under which investments by so-called socially responsible investors affect firm behavior in a setup in which firms generate negative externalities and face financing constraints. They demonstrate the complementarity between socially responsible and financially motivated investors, in the sense that together they can achieve a higher welfare than either investor type alone. The optimal financial contract in the presence of socially responsible investors can be implemented by combining a regular bond and a green bond which contains a technology-choice covenant specifying the technology to be adopted. An alternative implementation of the optimal financing agreement is a dual-share class structure with voting and non-voting shares.

Barbalau and Zeni (2022) study security design in particular, by focusing on the role of contingencies in enforcing commitment to non-pecuniary outcomes, generically called green outcomes. In the model they propose, firms are not a pass-through implementing the mandates of heterogeneous groups of investors but agency frictions play an important role. Investors value so-called green outcomes but firms dislike exerting the costly effort needed to deliver these outcomes. Firms seek to finance projects that yield uncertain green outcomes and can do so by issuing plain vanilla debt, contingent green debt or non-contingent green debt. Non-contingent green debt contracts are similar in spirit to green bonds, in that they pledge proceeds to specific green projects and yield a fixed return to investors. Contingent green debt contracts are similar in spirit to sustainability-linked bonds, in that they do not impose ex-ante restrictions on the use of proceeds but insure commitment to outcomes by making investors' return contingent on the realized sustainability performance of the issuer. The contingent debt contract is optimal if sustainability outcomes are perfectly measurable and cannot be manipulated. However, if contingencies depend on measurement systems which can be manipulated the non-contingent contract becomes optimal. The two types of green debt co-exist in equilibrium if green outcomes are manipulable and firms differ in their ability to manipulate.

Another way contract design can be used to incentivize agents to exert effort when implementing long dated socially oriented projects is through the use of employment contracts. Adachi-Sato (2021) studies how principals can use the length and timing of wage contracts to motivate profit maximizing managers to pursue so-called socially responsible investment. The paper builds on the multi-task principal-agent model of Holmstrom and Milgrom (1991) and considers an effort allocation problem whereby observable but unverifiable effort is allocated between a verifiable output component that incurs social costs, and an unverifiable output component that reduces social costs. Possible compensation contracts are a short-term wage contract that determines the second period wage at the beginning of the second period (ex-post bargaining) or a long-term wage contract that determines the second period wage at the beginning of the first period (ex-ante commitment). These contracts can be conceptualized as a contingent/non-contingent wage contract, respectively. A short-term (contingent) wage contract is more likely to be employed if the unverifiable output component substantially contributes to reducing social costs. However, if the unverifiable output component does not substantially contribute to reducing social costs, the more likely it is that the principal will offer a long-term (non-contingent) wage contract.

Empirical evidence on how impact is incentivized contractually is provided by Geczy, Jeffers, Musto, and Tucker (2021). They analyze the compensation contracts of impact funds and are able to obtain an insight into the extent to which contracting is done on impact versus financial performance. The paper documents that impact funds generally choose not to tie compensation to impact but adapt other elements of the contract to channel effort toward impact. Other such elements are participatory governance terms (enhanced monitoring), due diligence process and impact metrics (flexible contracting dictating process not outcomes), advisory committee roles, or more oversight. Contracting on impact is more flexible than contracting on financial performance, with contract terms devoted to impact often taking a more flexible form, focusing on process and reporting rather than impact outcomes directly. The authors conclude that it remains a puzzle why funds prefer other contractual constraints to the alternative of untying compensation from financial performance.

Despite increased investor interest, the sustainable finance market is limited in its growth by the limited availability of reliable information and measurement systems. An important issue is that of greenwashing, which refers to firms engaging in selective disclosure and manipulative practices in order to inflate perceived sustainability performance or to portray investment projects more sustainable than they actually are. There is a low level of convergence between the scores produced by different ESG rating agencies, and this seems to be mainly driven by measurement frictions (Berg, Kölbel, and Rigobon, 2019). Concerted efforts by regulators and international organizations are underway to develop reporting standards and mandate disclosure. The increasingly important role played by financial markets in the transition to a sustainable economy has opened the possibility that they are used as a tool, alongside government regulation, to address sustainability challenges such as reducing carbon emissions. Understanding not only the role of security design, but also the interaction between investment mandates, carbon markets and taxation is an important avenue for future research.

9. Concluding Remarks

Security design is concerned with deriving optimal contractual mechanisms for achieving specific outcomes in the face of frictions between agents. Broadly speaking, the outcome that financial security design aims to achieve is allowing agents to move funds freely across time, space, and possible outcomes, be it for the purpose of financing new ventures, managing existing ones, or making possible trade in previously unavailable contingent claims. This paper starts by reviewing studies that consider security design from a corporate financing perspective by focusing on how firms finance their operations and how the cash flows generated by the firm are allocated to its financiers. From a corporate governance perspective, security design deals with the allocation of voting and control rights to various classes of securities, as well as enabling the contingent transfer of control rights across security classes conditional on certain events or states of the world. A special class of securities are convertible securities that enable converting one type of security to another one that comes with a different set of cash flow and voting rights. In the aftermath of the financial crisis of 2007-2009, convertible securities that enable converting debt to equity conditional on pre-specified contingencies, have made the subject of extensive academic and regulatory debates as a means to recapitalize and stabilize large financial intermediaries. Financial intermediaries can profit from designing new securities and setting up new markets which enable agents to trade and hedge risks they were previously unable to, and which cater to the risk preferences of the suppliers of capital. Despite all these benefits of innovation, security design can and has been used to take advantage of investor's limited ability to understand complex security designs, and innovations such as securitization have been pointed out as having played an important role in causing the crisis. However, optimally designed securities can enhance welfare, can be used as a tool alongside government regulation to contribute to financial stability and, more recently, have been used as a tool to finance the transition to a sustainable economy. The literature looking into how financial markets and security design can contribute to financing projects that yield environmental, social or sustainability-related outcomes is fairly small but has grown in importance in recent years. The change in investor preferences, who now seem to value monetary as well as non-monetary outcomes, has been an important factor driving financial innovation and security design in the sustainability space. Finally, this paper also reviews how fintech and technological innovations have brought about new contracting possibilities in corporate finance and financial markets, by not only changing but expanding the ways in which security design can be used to finance and govern organizations, digitally represent securities and eliminate some contracting frictions such as the need for costly verification, enforcement or settlement. A common theme underlying these various application of security designs in finance is the issue of embedding contingencies in security design, which can be thought of as changing security features conditional on specific states of the world. Although in theory it is optimal to design securities that include all possible contingencies, this might not be possible in practice but whenever possible it is important to understand and overcome the frictions that prevent introducing welfare-enhancing contingencies in financial securities.

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