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Security design: A review☆

Franklin Allen [a,*], Adelina Barbalau [b]

[a] Imperial College Business School, London SW7 2AZ, United Kingdom
[b] Alberta School of Business, University of Alberta, Edmonton T6G 2R6, Canada

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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, financial intermediation applications such as securitization and contingent capital, the interaction of market and security design, as well as emerging applications such as fintech, sustainable finance and healthcare finance. Future research is also discussed.

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 concerned with 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 such as securitization and complexity in financial markets, as well as issues related to current developments like fintech, sustainable or climate finance and the funding of biomedical innovation. 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 discusses the early foundational papers that have significantly influenced the literature. The introduction provides an informal overview of the paper. Fig. 1 below provides a graphical illustration of the key research questions addressed in each section, and the Appendix provides a more detailed outline, in tabulated form, of the key ideas and references covered in 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 generated cash flows 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

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* Corresponding author.
E-mail addresses: f.allen@imperial.ac.uk (F. Allen), barbalau@ualberta.ca (A. Barbalau).

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include all possible contingencies, but this is rarely observed in practice. Numerous 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. One significant theory, the pecking order theory, explains the optimality of debt in terms of its lack of sensitivity to the issuers' 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, allowing for Knightian uncertainty and approaching the security design problem from the perspective of the competing, differentially informed suppliers of capital. We also review theories of debt and capital structure based on moral hazard, costly state verification and mechanism design. Whereas the pecking order theory is based on ex-ante asymmetric information, these theories have as a common theme the ex-post nature of asymmetric information, in the sense that the effort, action or outcome that a principal delegates to an agent cannot be perfectly observed or verified. Debt arises because verification frictions prevent the introduction of contingencies in contracts, or as the implementation of optimal, abstract mechanisms that are designed to align incentives. Mechanism design theories of optimal securities provide a broad framework for designing financial instruments that achieve efficient outcomes and address information asymmetries in various economic settings, including corporate financing and capital structure.

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, such as renegotiation or bankruptcy. 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 multi-class share structures. The allocation of control rights during unfavorable states of the world involves the transfer of control across classes of securities, typically from equity to debt holders, rather than allocation of control to securities. In this context, security design typically enables making the transfer of control contingent on the failure to make payments or on performance. However, the allocation of control and/or cash flows rights can be made contingent on any observable state. Convertible securities are a special class of securities, typically taking the form of debt or preferred stock, which embed an option to convert to common equity. In other words, they implement state-contingent rights allocation by enabling 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 that is special because it requires effort from both the financier and the borrower, which is modeled as a double moral hazard environment.

Section 3 reviews studies at the intersection of security and market

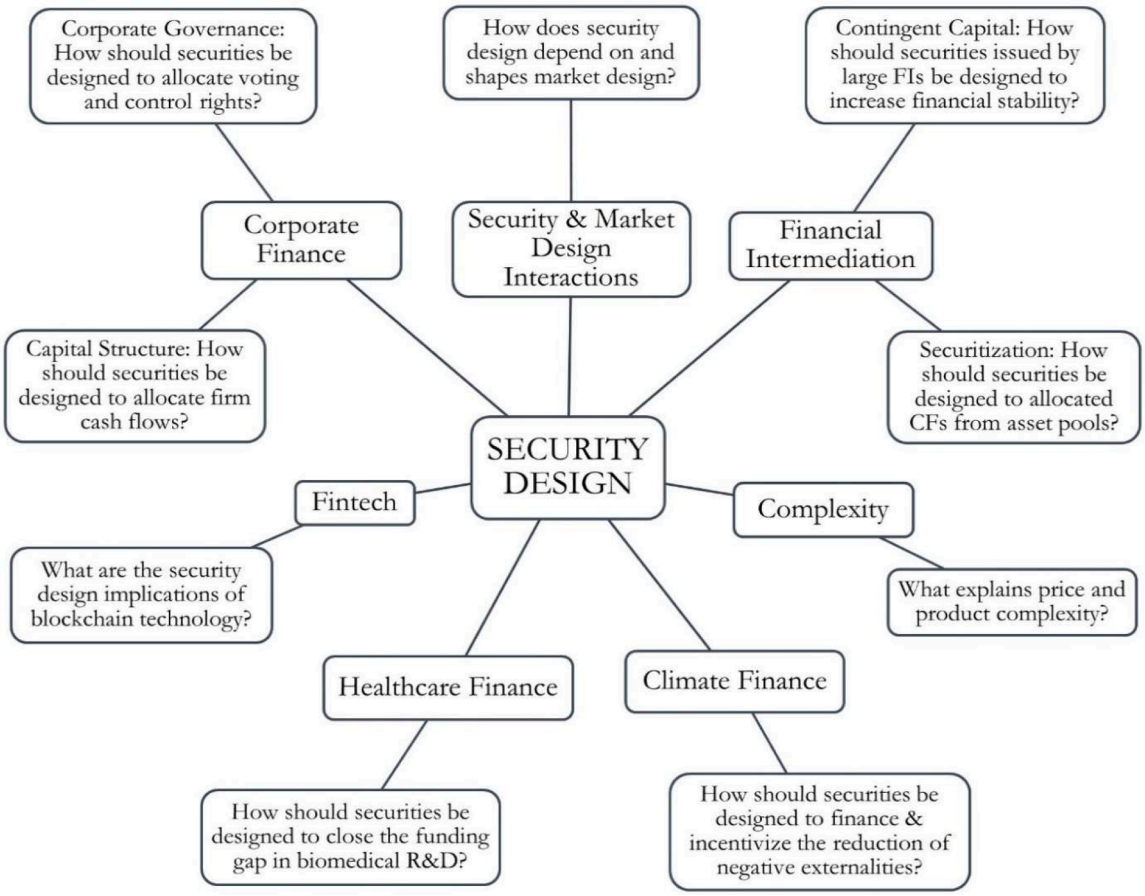

Fig. 1. Key areas and questions.

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. Whereas most papers reviewed in Section 2 study the optimal issuance of securities while taking security design as given, the papers reviewed in this section focus on the question of how securities should be optimally designed in the face of market frictions. Given that the notion of optimal security design relies on markets being incomplete, a number of papers derive optimal securities given various frictions that make markets incomplete, such as transaction costs, marketing costs and imperfect cash flow pledgeability. Market incompleteness creates incentives for agents to innovate as value typically accrues to the innovators. 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. An important incentive behind innovation is the desire to introduce securities that improve risk sharing, which has positive implications from a risk management perspective but may not be welfare enhancing because such securities also create opportunities for speculation. Concerns have also been raised about the redundancy of derivatives, but the existence of seemingly redundant securities can be rationalized through information frictions, collateral frictions and price impact. The introduction of new securities can also make markets more efficient through the production and incorporation of information, but increased market efficiency does not necessarily improve welfare as it can increase market instability. Another important incentive behind financial innovation is market segmentation, in the sense of limited investor participation. This 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 4 covers security design issues related to the operation of financial intermediaries (FIs), discussing on the one hand the creation of financial securities by FIs and on the other hand issues related to their capital structure. Section 4.1 covers the design of securities created by FIs, which govern the allocation of cash flows generated by underlying pools of assets rather than the allocation of cash flows generated by firms. Specifically, it covers securitization, the process by which FIs 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 pooling and tranching. Whereas pooling refers to the choice of financial assets to pool and sell to an entity called a special purpose vehicle, tranching deals with the choice of how to allocate the cash flows generated by the pool of assets to various categories of investors. 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 allows creating securities that appeal to investors with different preferences, and which have a higher marketability, as it enables dividing cash flows by credit risk, time to maturity, duration and other group characteristics. Tranche retention choices signal sellers' private information about the quality of the pool, and appropriately designed retention schemes can be thought of as a regulatory tool as they can be used to mitigate adverse selection and moral hazard. When it comes to governance issues related to securitization, the question is which tranche should control liquidation and renegotiation. Empirical evidence supports the theoretical predictions on the relative efficiency of subordinated security holders' control.

The capital structure of FIs is notably different from that of traditional corporations, because FIs have significantly lower levels of equity funding, referred to as capital, which makes them more susceptible to bankruptcy risk. Section 4.2 reviews proposals for contingent capital, which call for large FIs 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. 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. 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, and conversion ratios that dilute issuer's equity holders generate incentives to preemptively raise equity capital to avoid triggering conversion. Importantly, the type of contingent convertible bond design that has actually been issued by banks is one that favors equity holders, and which goes against most theoretically optimal designs proposed in the literature. Regulatory-compliant contingent capital implementations have triggers based on a book value capital ratio, which raises concerns as to whether they will trigger before the bank is insolvent. There is evidence that markets did not perceive them as going-concern contingent capital, suggesting that they offer no risk absorption before default, nor any preventive effect. Recent market developments put the whole contingent capital experiment at risk, since the March 2023 run on Credit Suisse resulted in shareholders retaining around $3 billion of equity value, while contingent convertible bond holders suffered a $17 billion principal write-down.

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 process information fully and rationally. 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 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 as 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. 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 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. Finally, 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. Furthermore, 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.

In Section 7 we review the literature at the intersection of security design and sustainable or climate 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 have seen 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 which 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, as well as the role of linking executive compensation to sustainability goals. Empirical studies provide mixed evidence on the impact that can be achieved through financial markets, and a number of theoretical papers highlight the dangers of delegating the task of curbing negative externalities to financial markets.

Finally, Section 8 covers security design issues related to the financing of biomedical innovation. The provision and development of healthcare are critical for individual health and economic welfare, and depend importantly on the funding of biomedical research and development (R&D). Despite its importance, there is significant underinvestment in biomedical R&D relative to the social optimum, which is due to a persistent R&D funding gap. Financial intermediaries, through the use of financial innovation and security design can play a key role in increasing the funding of biomedical research and closing this gap. The literature has mainly focused on securitization-based solutions, but options-based security design implementations have also been proposed. Solutions like the so-called megafund approach involve pooling multiple biomedical projects into a single financial vehicle which is to engage in securitization and issue tranches of debt as well as equity to finance the development of the underlying portfolio of pipeline drugs and their associated intellectual property. Other financial innovations, like "FDA Hedges", function as insurance contracts paying out when a drug project fails to gain FDA approval and can thus contribute to reducing underinvestment in R&D. Government assistance, complementing these financial innovations, can also play a role in increasing the flow of capital to the biopharma sector.

A large body of research has focused on explaining empirically observed security designs and issuance patterns by asking: Why are securities designed the way they are? There is also normative research which asks: How can securities be optimally designed to achieve certain outcomes and overcome frictions? This highly simplified way of synthesizing security design research suggests that it has been a primarily theoretical endeavor. We have aimed to provide a balanced review of theoretical and empirical work, but some sections have a stronger theoretical tilt than others. Our contribution is to provide an overview of the wide range of applications and implications of security design. We aim to provide a framework for structuring thoughts and ideas around how security design has interacted with major areas of finance research. In doing so, we have taken a bottom-up approach and grouped research based on categories or themes that seemed to emerge from the works reviewed. As a consequence, the corporate finance section is structured around the frictions that seem to have driven research in this literature, whereas in the securitization section the exposition was structured along the steps of the securitization process. Lastly, we note that despite our best attempts the review is not comprehensive and some papers could be categorized under more than one of the areas covered.

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 explore various frictions that explain empirically observed departures from this theoretical prediction. Below we review applications to corporate finance and structure our exposition around the frictions driving security design and corporate financing choices. Broadly speaking, we address the question: What are the implications of security design for corporate finance issues like financing, capital structure, and corporate governance?

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.[1] 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. In this subsection, we review papers that primarily address the first question, and which take a frictions approach to explaining the design of securities that firms issue to finance their operations. Research that has primarily addressed the second question, and which relate to optimal security design, is reviewed in Section 3.

Information frictions are an important class of frictions driving security design and capital structure choices. Information frictions create agency problems such as adverse selection and moral hazard, which are conflicts of interest arising because of misaligned incentives and goals of different parties. 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, 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 principal cannot freely observe or verify actions or outcomes ex-post. We first discuss what happens when there is asymmetric information ex-ante, and how the securities that firms issue depend on the nature of this information asymmetry. Then, we discuss implications of ex-post asymmetric information and issues related to the use of security design as a tool for aligning incentives. Some of the questions addressed are: What are the security design implications of information asymmetries between firm insiders and outsiders? How can security design be used to address adverse selection and moral hazard?

2.1.1. Ex-ante asymmetric information and adverse selection

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. A leading theory for the optimality of debt is the pecking order theory going back to 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 private information about the firm's future cash flows, 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 firm 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 adverse selection in which market participants draw inference about the productivity types of security issuers from the contracts proposed. Debt financing is a pooling equilibrium outcome if and only if the productivity types of firms can be ordered. 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 and show that non-contingent contracts are chosen in equilibrium because they do not reveal any information about the party proposing the contract.[2]

2.1.1.1. Relaxing the assumption that outsiders are relatively less informed. 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. But what happens if this assumption is relaxed? Rahi (1996) shows that with rational investors who use market prices to infer the private information of insiders, the optimal security is equity. In this setup, firm insiders have no privileged information, the hedging motive is the prevailing one and as a consequence equity is optimal because it allows efficient risk-sharing. 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.

What are the implications of reversing the typically assumed nature of the information asymmetry, and allowing outside investors rather than managers that have superior information about the firm? This setup is studied by Axelson (2007) and captures situations such as those of 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 if competition is high equity backed by individual assets is optimal.

What are the security design implications of allowing agents to acquire information? Yang and Zeng (2019) consider the case when 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 investors have 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 depends on the importance of information for production and can be either debt or a combination of debt and equity. 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.

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

[2] Holmström 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.

2.1.1.2. Further asymmetric information refinements. Empirically, various violations of the pecking order theory have been documented (Frank and Goyal, 2003; Fama and French, 2005; Leary and Roberts, 2010; Frank et al., 2020). The pecking order theory predicts that due to adverse selection, firms' preferred sources of financing are internal resources, followed by debt and as a last resort external equity. Empirical evidence suggests that small high-growth firms do not behave according to the pecking order theory and display a preference for issuing equity rather than debt. This is surprising because small firms are often thought of as firms with large information asymmetries. Instead, the predictions of the pecking order are best matched in samples of large firms, that are not usually considered to be firms affected by adverse selection problems.

This evidence has raised questions regarding the frictions that can rationalize such violations. These include asymmetric information refinements such as accounting for multiple sources of cash flow uncertainty and relaxing the assumption that agents know the probability distribution generating uncertain outcomes or, in other words, accounting for Knightian uncertainty or ambiguity. Fulghieri et al. (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 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. These predictions are in line with evidence by Frank and Goyal (2003) and Fama and French (2005) that small, high-growth firms typically rely heavily on outside equity rather than debt for financing, despite the fact that this is a class of firms which is presumably more exposed to asymmetric information.

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 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. In this model, 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. The model predictions are in line with evidence that mature firms, which derive their value mostly from assets in place, have a preference for debt rather than equity financing (Shyam-Sunder and Myers, 1999). On the other hand, for young, high-growth firms which are more likely to derive their value from uncertain new projects, equity is optimal particularly when the uncertainty is large (Frank and Goyal, 2003; Leary and Roberts, 2010).

Chaigneau (2022) introduces two dimensions of uncertainty, about the upside and the downside potential of an asset and allows different investors to be informed about these two dimensions. Two capital structures are possible. A capital structure with two information-sensitive securities, equity and risky debt, are optimal for information revelation purposes, as the two securities are exposed to a different dimension of uncertainty and their market prices can each reveal a different type of information. A capital structure with only one information-sensitive security, equity, can be optimal when investors are less informed about the dimension that matters more for valuation.[3] This latter prediction rationalizes why innovative firms with a large upside subject to strong information asymmetries often have abnormally low leverage and is in line with empirical evidence on the "zero leverage puzzle" documented by Strebulaev and Yang (2013), who show that an average 10.2 % of large public non-financial US firms have zero debt. These firms with zero leverage tend to be more R&D intensive, have a higher market-to-book ratio, less capital expenditure and less tangible assets, which is suggestive of innovative firms which are subject to especially strong information asymmetries about their upside potential.

Another asymmetric information refinement, which represents a departure from the rational expectations paradigm that has been used to rationalize the optimality of debt, is adaptive learning. Noe et al. (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.

2.1.1.3. Security design from investors' perspective. Having discussed the implications of shifting the information advantage from insiders to outsiders brings us closer to a change in perspective from firms wanting to raise capital to financiers seeking to invest. Although the corporate financing literature has placed a lot of emphasis on the firm problem, the problem of investors is equally important and raises questions such as: How should the problem of designing securities be thought of from the perspective of the suppliers of capital? What securities will financiers offer to obtain a stake in a firm or an investment opportunity more generally? Why do different types of financial intermediaries offer different financing contracts? What is the role played by competition and differences in the competing agents' information sets?

The security that an investor offers to invest in a project reveals information about the bidder's valuation, with implications for competition. Fishman (1989) considers an informed investor who trades off the advantage of offering cash to deter competition from uninformed investors, against that of investing through a risky security such as equity, which induces the entrepreneur to make an efficient accept or reject decision. Inderst and Mueller (2006) examine how securities should be optimally designed when lenders want to minimize inefficient accept or reject decisions after screening projects. Screening generates a private, informative signal about the project's profitability and the cutoff signal above which the lender accepts or rejects the project might deviate from the first best. Debt is optimal when the lender is too conservative, meaning that the cutoff is too high, whereas if the cutoff is too low the optimal security is equity. The model predicts that debt is optimal for relatively safer projects that break even based on public information. This prediction is in line with empirical evidence that banks typically hold debt, while venture capitalists hold more equity-like securities (Kaplan and Strömberg, 2003).

[3] This paper is related to and extends Boot and Thakor (1993), where the capital structure is designed to maximize information revelation via security prices, by allowing assets to differ along two dimensions of uncertainty. We discuss Boot and Thakor (1993) in relation to securitization in Section 4, and also note that the results of Chaigneau (2022) can also be applied to securitization and rationalize tranching into equity and several tranches of debt and do so without moral hazard or market illiquidity.

Both Fishman (1989) and Inderst and Mueller (2006) consider an informed investor's security design under competition from uninformed investors. But what if all investors are informed? DeMarzo et al. (2005) consider a model in which privately informed investors compete for an investment opportunity whose value is different under investments from different bidders. In other words, bidders' private signal is informative about the value of the project under their own investment. In order to signal high private values, they retain as much exposure to the uncertain project value as possible, by requesting securities with high information sensitivity as compensation for their investment, while offering information-insensitive sensitivity securities such as cash or debt to the entrepreneur seeking financing. On the other hand, Yuan (2022) considers a setup in which bidders compete for an investment opportunity whose value is common across bidders. Under common value competition, privately informed bidders still have new information to learn about the project value from other bidders' private signals. In this setup, it is optimal to offer the entrepreneur securities that are highly sensitive to the project value and request the security with the lowest information sensitivity as their own compensation.

Closely related to that of how securities for firm financing should be designed is the question of how securities for firm acquisition should be designed? When it comes to acquisition rather than financing, an important role is played by the (asymmetric) information regarding the value added coming from the acquisition or the merger synergies between the two parties, and not only their standalone values. Jansen et al. (2021) study optimal security design for firm acquisition in a setup where insiders have the information 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. Liu and Bernhardt (2021) propose a target-initiated theory of takeovers where target firms approaching potential acquirers have an information disadvantage and it is outsiders that are relatively more informed. 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 under certain circumstances.

2.1.2. *Ex-post asymmetric information and moral hazard*

Having reviewed papers belonging to the large literature that justifies the optimality of debt based on adverse selection, we move on to discussing papers covering alternative theories. Specifically, we review theories of debt and capital structure based on moral hazard, costly state verification and mechanism design. These have as common theme the ex-post nature of asymmetric information, in the sense that the effort, action or outcome that a principal delegates to an agent cannot be perfectly observed or verified. The focus of security design is on aligning the interests of different parties so as to achieve efficient outcomes and reduce agency issues.

Moral hazard is another important friction that can rationalize the optimality of debt. The main idea behind the theories of optimal debt based on moral hazard is to strike a balance between the benefits and costs of issuing debt. Although debt can discipline borrowers and reduce moral hazard by imposing contractual obligations and monitoring mechanisms, excessive debt can exacerbate moral hazard by providing borrowers with incentives to take on excessive risk or engage in opportunistic behavior. Security design aims to incentivize agents to take the right action and involves carefully balancing the trade-off between providing incentives for efficient behavior and controlling the costs of those incentives. Innes (1990) studies the optimal contract offered by a principal that aims to induce effort in a contracting framework in which a firm's liability to its security holders is limited to the firm's assets and profits. When no constraints are placed on the form of the financial contract, limited liability leads to a so-called "live--or-die" contract, which entails that the investor takes a constant share of the firm profit when this profit is less than some critical level and nothing when the profit is higher. Using such a contract that gives the entrepreneur maximal payoffs in high profit states, the entrepreneur is induced to choose maximal effort. On the other hand, if the investor's payoff function is constrained to be nondecreasing in the firm's profit, the optimal monotonic contract is standard debt. In the model proposed by Innes (1990) the seller can exert effort to improve the distribution of outcomes but cannot increase the risk to the investor. Hébert (2018) takes into account both effort and risk-shifting. He studies static and dynamic security design in a moral hazard setup in which the seller of the security can create any probability distribution of outcomes, subject to a cost. Specifically, the entrepreneur can alter both the mean value of the outcome ('effort') and change the other moments of the distribution of outcomes ('risk-shifting'). It is shown 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, and among all limited liability securities with the same expected value, debt securities have the least variance. The technology or action space that agents have access to in such moral hazard contracting frameworks has important implications for the form of optimal contract and financing. Starmans (2023) examines the relationship between firms' financing constraints and the production technologies that they have access to. He provides a complete characterization of optimal contracts, agency rents, and the investor's investment decision when entrepreneurs have access to heterogeneous production technologies that generate different probability distributions of outcomes under effort. Differences in production technologies imply differences in optimal contracts and agency rents across equally productive entrepreneurs, which ultimately give rise to financing constraints. The optimal contract is a linear combination of tranches, with the more junior tranche paying off only in high states and the more senior tranche paying off also in lower states.

2.1.2.1. *Costly state verification.*

Moral hazard arises because actions or outcomes cannot be perfectly observed or verified. But what if outcomes can be verified at a cost? This is the idea behind the costly state verification literature, which aims to address information asymmetry problems in principal-agent relationships by incorporating the costs of verifying the agent's actions or outcomes into the contract between the two parties, thereby reducing the risk of moral hazard.

Townsend (1979), Diamond (1984) and Gale and Hellwig (1985) derive standard debt as the optimal contract from first principles using costly state verification as the relevant contracting friction. In Townsend (1979), 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 rules governing 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) show that profit manipulation opportunities move optimal contracts from debt toward equity-like arrangements. Koufopoulos et al. (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. 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.

What if outcomes can be perfectly observed and contracted upon? Debt is the optimal incentive-compatible contract when there is incomplete information, but this does not explain why the debt contract does not make repayments contingent on readily available information. Having already discussed papers that explore frictions that prevent implementation of contingencies, we now discuss how the availability of performance signals affects contracts. Specifically, we discuss performance-sensitive debt, a class of securities that make the allocation of cash flows contingent on performance outcomes. Chaigneau et al. (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 the 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 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 et al. (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. They also provide empirical support to this screening hypothesis, by documenting that borrowers with loans that have performance-pricing provisions are 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.

What is the empirical evidence on the use of performance-sensitive debt? Begley (2012) 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 et al. (2005) study how adverse selection and moral hazard interact with 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[4] costs are higher and downgrades are more likely. On the other hand, interest-decreasing performance pricing is more common when adverse selection[5] costs are higher, prepayment is more likely, and less common when multiple performance measures better predict credit quality. These findings suggest that performance pricing provides two contracting features that can be used to reduce moral hazard and adverse selection costs. Both borrowers and lenders benefit from the gains from interest-decreasing performance pricing. On the other hand, only the lender benefits from the gains from interest-increasing performance pricing, while the borrower is compensated with a lower interest rate to participate.

2.1.2.2. Mechanism design. The literature on mechanism design provides a general framework for dealing with moral hazard in principal-agent relationships, which aims to create efficient solutions for aligning incentives by designing abstract mechanisms, i.e. optimal contracts, which are then implemented using combinations of existing securities. The problem is that of a principal facing information asymmetry, who seeks to incentivize the agent to exert the appropriate effort levels over time, or to prevent the agent from diverting output for his private benefit. Mechanism design theories of optimal securities provide a broad framework for designing financial instruments that address information asymmetry and promote efficient outcomes in various economic settings, including debt contracting.

DeMarzo and Fishman (2007) derive debt and equity as optimal securities in a discrete-time dynamic principal-agent model of financial contracting in which agents can divert cash flows or consume other private benefits. 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 et al. (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 (2006) 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 and 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.[6]

Ambiguity aversion has also been explored in such mechanism design setups. What are the contracting implications of ambiguity aversion, which implies a concern for worst-case outcomes? The typical finding is that ambiguity aversion leads to contract implementations that feature contingent payoffs. Miao and Rivera (2016) build on the DeMarzo and Sannikov (2006) continuous-time agency model with hidden action and consider a situation in which the principal has

[4] 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.

[5] 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.

[6] The provision of liquidity through credit lines and the role of syndicates is studied by Santos and Viswanathan (2024).

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 et al. (2021) extend this model to allow for early liquidation and show that it can be optimal for the agent to terminate the long-term contract early when the principal is sufficiently ambiguity averse. 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 principal's concern that the entrepreneur may be overly optimistic. Both these papers focus on ambiguity surrounding mean project cash flows. But what are the implications of ambiguity about cash flow volatility? Hansen (2022) studies precisely this question in the context of a model of optimal contracting under moral hazard. Relative to the implementation in DeMarzo and Sannikov (2006) 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.

Szydlowski and Yoon (2022) rationalize the implementation of performance-sensitive debt in a continuous-time principal-agent model in which the principal is ambiguity averse about the agent's effort cost. After sufficiently high performance, the worst-case scenario is that effort cost is high, which implies that, in expectation, the agent receives higher payouts than in the case without ambiguity. On the other hand, after low performance, the worst case is that effort cost is low, and the agent is undercompensated. The optimal ambiguity-robust contract generates a seemingly excessive pay-performance sensitivity and provides a new explanation for why high performing managers receive seemingly excessive compensation, in terms of principal's ambiguity aversion. However, ambiguity-aversion does not always predict the inclusion of contingencies in optimal contracts, but this also depends importantly on what the objective or purpose of the contract is. Carroll (2015) shows that when the principal proposes a contract meant to guarantee a positive expected payoff and it faces uncertainty about the set of actions taken by the agent, 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. Thus, a concern for robustness and worst-case scenarios predicts that the linear contract is optimal.

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 entering the contract. We will first discuss the allocation of control rights 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. Then we discuss the transfer of control rights across different securities, which has to do with governance in unfavorable states of the world and most often takes the form of transferring control to debt holders.

2.2.1. Allocation of voting rights

In this section, we discuss security design issues which have implications in terms of how firms manage their day-to-day activities, or governance in the normal course of operations. We address questions such as: How should voting and cash-flow rights be allocated to securities? How should this allocation be designed to manage conflicts of interest between different investors or alternatively stated, different classes of securityholders?

Grossman and Hart (1988) address the question of how voting rights should be assigned to securities from a corporate control contest perspective. Building on the premise that a firm with securities that are widely held is effectively run by the incumbent management, they study the implications of voting rights allocation for incumbent and rival management teams. 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, with one-share-one-vote being socially optimal, whereas 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 current and prospective investors. Can security design and the allocation of control rights be used to resolve conflicts of interest between incumbents and contestants for control? Harris and Raviv (1989) study this question, show that the optimal security is a single voting security and generalize the result on the optimality of one-share-one-vote. 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.

A review of the theoretical literature on security-voting structure is provided by Burkart and Lee (2008). They examine the extent to which the theoretical literature substantiates the optimality of one-share-one-vote and analyze the implications of mandating one-share-one-vote for firms' financing and ownership choices. The standard justification in favor of one-share-one vote is that agents with the strongest interest in maximizing firm value are also in control, which prevents the pursuit of self-serving actions at the expense of firm value. However, one-share-one-vote also comes with disadvantages as it may deter entrepreneurs from going public to avoid the risk of losing control which can distort investment strategies or inhibit firm growth. It also makes it more expensive to acquire or exercise control and thus exacerbates the free-rider problem in dispersedly held firms. Thus, it is unclear whether mandating one-share-one-vote has positive corporate governance implications. This is even more so since deviating from one-share-one-vote has been argued to grant immunity against proxy contests initiated by short-term investors and allow managers to fund

long-term investments whose value might be difficult or expensive to communicate to outsiders.

Multi-class shares have become one of the most controversial issues in today's capital markets and corporate governance debates. When a company goes public using multi-class share structures, it creates two or more classes of shares which differ with respect to their voting rights allocation. An example of dual-class structure involves issuing a class of stocks to the general public, often called Class A, which are used to raise capital and have a one-share-one-vote allocation. Another class of stocks, typically called class B, are reserved for founders and key employees and may allocate 10, 20, or more votes per share. Since Google adopted the model in 2004, increasingly more internet and technology companies have gone public with dual shares, including Facebook, LinkedIn, Snapchat, and Pinterest. Dual-class share structures disrupt the proportionality between voting and cash flow rights and allow companies to go public while simultaneously retaining control. Hu et al. (2012) document the use of dual-class share structure by Silicon Valley companies, and discuss the concerns about disproportionate control expressed in the academic literature.

Why do firms deviate from a one-share-one-vote regime when going public? Clearly, a dual-class share structure allows those in control at the initial public offering (IPO) to remain in control. But what exactly are they seeking to achieve by retaining control? Arugaslan et al. (2010) examine data on U.S. IPOs from 1980 through 2008 and find that managers appear to take their firms public with dual-class shares in order to retain control of their firms while reducing the costs associated with their lack of diversification. They find no evidence supporting alternative theories that deviating from one-share-one-vote allows managers to maximize the proceeds from any subsequent sale of control, or that it allows managers to fund long-term investments whose value cannot be communicated to outsiders. The empirical literature on the use of mechanisms that separate voting rights from cash flow rights in corporations is surveyed by Adams and Ferreira (2008), who also point to areas for future research. They focus on disproportional ownership, discussing mechanisms that allow some shareholders to acquire control with less than proportional economic interest in the firm, including dual-class shares, cross-ownership as well as takeover defenses and fiduciary voting.

What is the market response to multi-class structures, and should their use be regulated? Perhaps unsurprisingly, investors do not favor these designs. Kim et al. (2018) examine multi-class share structures around the world and provide evidence that institutional investors exhibit strong aversion towards multi-class firms, investing less in these firms and discounting their valuation. Furthermore, firms seem to respond to institutional investor preferences through the voluntary conversion to a single-class share structure. Gurrea-Martínez (2021) analyses several jurisdictions around the world and finds that the optimal regulatory approach to deal with dual-class shares depends on a variety of local factors. The paper argues that regulators should allow companies to go public with dual-class shares in countries with sophisticated markets and regulators, strong legal protection for minority investors, and low private benefits of control. By contrast, dual-class shares should be prohibited or subject to higher restrictions in countries without sophisticated markets and regulators, high private benefits of control, and weak legal protection for minority investors.

Other interesting topics in this research area, with important implications for corporate governance, are the markets for trading voting rights and the increased prevalence of proxy voting. Christoffersen et al. (2007) document an active market for votes within the equity-loan market and estimate that the average vote sells for zero. They find support for the hypothesis that asymmetric information motivates the vote trade by documenting that more trading occurs for higher-spread and worse-performing firms, especially when voting is close. They also find that vote trading is associated with support for shareholder proposals and opposition to management proposals. Understanding how vote trading interacts with current developments such as the increase in shareholder activism, disagreements on ESG-related matters and the purpose of the corporation, represent interesting research questions.

Another interesting trend is the unprecedented concentration of voting power among a few asset managers, which makes them pivotal in many public firms (Lewellen and Lewellen, 2022). A related issue is the widespread reliance on proxy voting, which has raised concerns that proxy advisory firms are granted significant market power to influence proxy voting outcomes. Recently, there have been major institutional and regulatory developments which involve fund managers offering their investors a choice between delegating their votes to the fund or casting votes themselves. Malenko and Malenko (2023) study the implications of voting choice for investor welfare and find that it depends importantly on whether the reason for offering voting choice is that investors have different preferences or that investors have information about the proposal that the fund manager does not have. Understanding the full implications of such trends, and their interactions with technology and changes in investor preferences are promising areas for future research.

2.2.2. *Transfer of control rights*

Whereas the allocation of control rights to securities can mainly be viewed as a way to mediate the relationship between investors, the transfer of control rights across securities plays an important role in mediating the relationship between management and investors. How should the allocation of control be optimally designed in the presence of conflicts of interest between managers and investors? Importantly, given that contracts are bound to be incomplete, who has the right to decide about events that are left out from contracts? In other words, who has residual control rights? The transfer of residual control rights to debt holders has been proposed as a way to protect investors against potential opportunistic behavior on behalf of managers. Hart and Moore (1998) emphasize 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. Worth noting is that in this setup there is no conflict of interest between equity holders and management, which are essentially treated as one and the threat of liquidation is the only disciplinary action that can be implemented through the allocation of control rights. Grinstein (2006) considers a setup in which liquidation or managerial replacement can be used as disciplinary actions and studies the role of debt as well as equity. The author shows both theoretically and empirically that the optimal allocation of debt, equity, and control rights depends on the efficiency of using managerial replacement or liquidation as disciplinary actions. Control rights should be allocated to equity holders when the efficient action is managerial replacement, and capital structure should consist of equity and long-term debt. On the other hand, when the efficient action is liquidation, capital structure should consist of equity and short-term debt and control rights can be allocated to the manager. 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).

Thus, the transfer of control can and is in fact made contingent on a number of events, and not just payment failures. 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 will have control 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. The contingent allocation of control rights is a central feature of financial contracts between venture capitalists (VCs) and entrepreneurs. Kaplan and Strömberg (2003) conduct a detailed analysis of control allocation in 100 VC contracts and document the prevalence of contingent control allocations, with control and liquidation rights being made contingent on performance, and with control also shifting between constituencies depending on performance.

Evidence suggests that financiers exert considerable control even in the absence of payment default and influence investment policy through the introduction of covenants and other restrictions in private credit agreements. We refer the reader to the review by Roberts and Sufi (2009b) of the empirical literature on credit control rights outside bankruptcy and only discuss a couple of relevant papers here. Chava and Roberts (2008) provide empirical evidence that transfer of control rights through debt covenants impacts corporate investment. Specifically, they document a sharp drop in capital investment following the violation of covenants in private credit agreements, particularly in situations in which agency and information problems are relatively more severe. Nini et al. (2009) provide evidence that explicit restrictions on firms' firm capital expenditures are regularly imposed in private credit agreements and lead to lower investment than would otherwise be observed. Such restrictions are also reflected in positive market valuations and operating performance, suggesting that they are value enhancing. The idea that the transfer of control increases firm is in line with the model proposed by Zender (1991), who makes the point that the state-contingent assignment of control across securities is a tool that facilitates cooperation between the contracting parties and broadens the firm's investment opportunity set. The state-contingent transfer of control relaxes an incentive constraint that would otherwise bind and enhances the value of the firm as a going concern. Equity and debt are derived as optimal securities in a model in which cash flows and control rights are allocated endogenously.

2.2.2.1. Governance in unfavorable states of the world. While the allocation of voting rights to various securities 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 is insolvent. When assets might not be sufficient to fulfill debtors' claims, 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. We first discuss papers that have studied security design in relation to renegotiation, and then cover those related to bankruptcy.

Renegotiation is a common occurrence. Roberts and Sufi (2009a) provide empirical evidence that over 90 % of long-term debt contracts are renegotiated prior to their stated maturity. Contingencies are found to play an important role in renegotiations, and the contractual assignment of bargaining power influences the renegotiation process in a state-contingent manner. So, how does the possibility of renegotiation affect the optimal contract? How does it affect contracting parties' ability to implement the first-best outcomes?

A number of papers have studied the implications that the possibility of renegotiation has in terms of the optimality of debt contracts and welfare. In many settings, renegotiation may prevent the implementation of first-best outcomes (Dewatripont, 1989; Hart and Tirole, 1988). For instance, in the presence of moral hazard, renegotiation restricts the ability of the contracting parties to structure incentives optimally. Focusing on the case of sovereign debt, where lenders' threat of verification and of imposing punishments for default may not be credible, Gale and Hellwig (1989) show that the possibility of renegotiation undoes the optimality of standard debt contracts and reduces welfare. However, renegotiation can also improve welfare. Gale (1991) shows that the possibility of renegotiating contracts makes them more contingent than they appear. Simple contracts are optimal in that their renegotiation will achieve efficient risk sharing ex-ante, before uncertainty is resolved. Worth noting is that the possibility of renegotiation often guarantees that the outcome of a contract is efficient ex-post, after the resolution of uncertainty, whereas the result in Gale (1991) establishes ex-ante optimal risk-sharing. However, the focus in this paper is to achieve the first-best allocation of risk when there is complete information and no moral hazard. Renegotiation also improves welfare when there is asymmetric information (Hermalin and Katz, 1990). Hart and Moore (1988) show that renegotiation provides a mechanism for making a contract effectively contingent on information that cannot be verified by a third party and can even achieve the first-best in some circumstances, though this is not generally true. Aghion et al. (1991) have extended the Hart-Moore analysis to show that quite simple mechanisms can achieve the first-best in some circumstances. Specifically, they point to the role of contractual renegotiation design, that is, the design of rules that govern the process of renegotiation, in achieving efficient investment and optimal risk-sharing. 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.

The empirical observation that contracts are often renegotiated and that contracts can differ with respect to the ease of renegotiation raises several questions. How does the possibility of renegotiation influence debt design and firms' financing choices? How can contracts that are robust to renegotiation be designed? Repullo and Suarez (1998) consider the role of informed and uninformed debt and determine the optimal renegotiation-proof lending contract. 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 bank debt, conceptualized as informed debt, is typically secured, senior, and tightly held.

Debt contracts can differ in terms of the ease with which they can be renegotiated. This raises the question: What are the capital structure and financing implications of debt designs that are heterogenous with respect to the ease of renegotiation? Hackbarth et al. (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 co-exist.

Bankruptcy is the ultimate bad state of the world for a firm, and it 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. How does the possibility of bankruptcy affect

firms' capital structure and the design of securities they issue? How does bankruptcy design interact with security design and capital structure choices? How should the proceeds obtained from the liquidation of the firm's assets be allocated to the various classes of creditors? Winton (1995) addresses this latter question and 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. When firms have a higher cash payout ratio, the security design tends to stress higher coupons and sinking funds.

The rules and procedures governing the bankruptcy process do not only have an impact on firms' capital structure choices but can also be embedded in the securities that firms issue. This raises questions related to the joint determination of bankruptcy and security design, as well as to the allocation of rights to trigger bankruptcy. Von Thadden et al. (2010) study the joint design of bankruptcy and debt contracts and make 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 larger than the available amount of verifiable assets, the debtor cannot fulfill them all and the role of bankruptcy is to adjust individual claims. They show 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. The model predictions are in line with empirical evidence on absolute priority violations (Franks and Torous, 1989; Bharath et al., 2010). Whereas in the 1980s absolute priority deviations (APDs) in favor of equity holders were occurring as often as 75 % of the time, the average frequency of APDs has decreased considerably. Based on a sample of bankruptcies from the period 1991–2005, Bharath et al. (2010) document that the average frequency of APDs has declined to 22 %. Perhaps unsurprisingly, APDs are more likely when management has substantial shareholdings in the firm. They argue that the secular decline in the frequency of APDs is driven by innovations in the bankruptcy process, such as reliance on debtor-in-possession (DIP) financing and adoptions of key employee retention plans (KERPs). When filing for bankruptcy, firms typically need to raise additional capital to operate while undergoing the reorganization process. This takes the form of DIP financing, which has become increasingly more stringent in recent years, with lenders designing contracts that ensure their super priority status. Additionally, KERPs are performance bonuses awarded to managers and key employees for faster reorganization which have likely contributed to the documented improvement.

In practice, the bankruptcy process in the U.S. is structured such that firms can choose to enter either Chapter 11 reorganization or Chapter 7 liquidation. Antill and Grenadier (2019) consider a realistic continuous-time dynamic bargaining model of optimal capital structure and bankruptcy choice, in which firms can choose to enter either Chapter 11 or Chapter 7. Chapter 11 reorganization can be thought of as a bargaining process between the firm and creditors who share control, where 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. A related and little explored area of research has to do with the capital structure and financing choices of municipalities, which are subject to renegotiation and bankruptcy procedures that differ markedly from those faced by corporations. Carlson et al. (2022) analyze how municipalities determine optimal financing, highlighting legal structures governing financial distress, and state-by-state variation in allowance of workouts under bankruptcy law. The important role that municipalities play in addressing issues of increasing importance such as rising social issues related to homelessness, drug addiction and systemic inequality, as well as infrastructure and adaptation investment needs caused by climate change, this represents a very important area for future research.

Roberts and Sufi (2009b) provide 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.

2.2.3. *Contingent allocation of cash-flow and control rights*

As discussed, the allocation of control and/or cash flows rights is not only contingent on default but also on performance. A special class of securities that allow for contingent allocation of cash-flow and control rights are convertible securities. Convertible securities implement performance-contingent rights allocation and typically take the form of bonds or preferred stock that can be converted into common stock. These securities give the holder the option to convert them into a predetermined number of common shares, and although conversion is not explicitly made contingent on performance, the holder will only find it convenient to convert if performance is sufficiently favorable. 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 et al. (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 for 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 model's predictions are in line with empirical evidence that convertible securities are more likely to be used by

startups than by established companies (Gompers, 1997; Kaplan and Stromberg, 2003) and that smaller public companies are more likely to issue convertible securities (Noddings et al., 2001; Brealey et al., 2010). These patterns are rationalized in terms of the venture's riskiness.

The use of convertible securities is particularly 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. So, what explains the observed prevalence of debt in double moral hazard environments such as venture capital? Schmidt (2003) demonstrates that convertible securities represent a powerful incentive mechanism which in the context of a sequential double moral hazard problem 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. 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. The payoff structure of these optimal securities resembles the equity- and convertible-like payoffs that are empirically observed in VC finance (Sahlman, 1990; Gompers, 1997). Hellmann (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 stock that allocates different cash flow rights depending on whether exit occurs by acquisition or through an 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. VC deals often use preferred stock instead of debt to give outside investors priority and high-powered cash flow incentives. Kaplan et al. (2007) analyze VC investments around the world, discussing the prevalence and role of incentives provided by convertible securities. While their usage is notable globally, there are contrasts in the application and structure of these securities between U.S. and non-U.S. countries.

In this section, we have reviewed security design applications to the field of corporate finance. We discussed separately studies that consider security design issues related to corporate financing, where security design is mainly related to the allocation of cash flows, and those related to corporate governance, which is mainly concerned with the allocations of control rights. When it comes to corporate financing and the allocation of cash flows a lot of research has been dedicated to rationalizing the observed optimality of debt and exploring a great number of asymmetric information environments. Theories based on ex-ante asymmetric information place information-sensitivity at the heart of security design. Theories based on ex-post asymmetric information regard securities as a mechanism for providing and aligning incentives and explore a trade-off between the benefits and costs of providing incentives. The allocation of control rights has to do with corporate governance. Voting rights are allocated to securities to govern the firm during the normal course of operations, and they are transferred across securities to manage unfavorable states of the world such as renegotiations and bankruptcies. Convertible securities implement state-contingent allocation of control and cash flow, and efficiently address challenges in environments with double moral hazards, such as VC, by promoting both parties' active involvement.

In the field of corporate finance, a major development is the rise of stakeholder capitalism, which holds that corporations should serve the interests of all stakeholders. The corporation's objective function should be to maximize aggregate welfare, and not shareholder value (Hart and Zingales, 2017). But how can this be implemented? How can a firm's objective function be changed to maximize aggregate welfare? This requires a paradigm shift and challenges the dominant corporate governance paradigm based on shareholder value maximization but is in line with the observed increase in shareholder engagement on environmental and social issues, and the increase in ESG investing. Hart and Zingales (2017) argue that this can be implemented by allowing pro-social shareholders to vote on corporate policy. In other words, it is through corporate governance channels. This raises questions about the allocation of control rights and the role of large institutional investors that have sizeable holdings in most public companies and are often pivotal. Despite concerns about their excessive power, such large investors can be conceptualized as universal owners, who are effectively exposed to the global economy and as a consequence have a vested interest in the overall health and sustainability of the global economy, not just the performance of individual companies. As such, they have been argued to have an objective function that approximates that of a planner intent on maximizing social welfare. Big international corporations can also play an important role in promoting sustainability, by diffusing their corporate governance standards across countries and driving change in places where it would likely not happen otherwise. They also have superior access to capital, can tap into varied capital markets, and can contribute to their development through the issuance of innovative securities, including output-contingent green securities that are specifically designed to tackle climate change. Also worth noting is the increasing pressure placed on public corporations to solve social problems, which has created backlash and an increased reluctance on behalf of companies to go public. By staying private, companies can escape shareholder and regulatory pressure, thus raising questions around alternative levers that can be employed to change the objective function of such companies.

Another interesting development has to do with the rise of big data, technologies that process data, produce information, and automate decision-making, to name a few. As we discussed at length in this section, information frictions are of great importance when it comes to corporate financing and governance. How will the increase availability of data and the rise of machines that process and produce information affect corporate decision-making processes? How shall we think about decision-making by humans and machines? What are the implications of substituting human decision-making with machines and automated decision-making? This is a research area that is ripe with open questions. We will return to discussing the interactions between corporate finance and fintech in Section 6.

3. 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. In this section, we start by discussing theories of optimal security design, which require that markets must be incomplete.[7] The study or notion of optimal security design is only relevant in incomplete markets, because when all risks can be traded the design of securities issued is irrelevant. We then move on to discussing incentives to innovate that are driven by market incompleteness, touching upon security innovations that improve risk management, create opportunities for speculation or are seemingly redundant. Lastly, given that through security design innovations new markets are created, we discuss the interaction between security and market design.

3.1. Market incompleteness and optimal securities

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. So, what are the frictions leading to market incompleteness which in turn warrant the study of optimal security design? 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 optimally 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 exist, with the implication that 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. This extremal security design is not one that is seen issued in practice. Gale (1992) offers an explanation for why firms may not use these securities in terms of the cost of gathering information about unfamiliar securities that investors face. Thus, firms issue standard securities that are issued by other firms and with which investors are already familiar. Worth noting is that to support standardization as an equilibrium phenomenon, information must be non-transferable and generic, that is, not revealed by prices or the observation of other agents' decisions and useful in evaluating a number of securities.

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. Taking an asset pricing focus, Biais et al. (2021) propose a theory of endogenous market incompleteness, leading to market segmentation, which is 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, agents value assets differently at the margin and they hold strictly different portfolios. In other words, there is endogenous segmentation, and the focus of this paper is on the equilibrium consequences of such endogenous segmentation.

Thus, market incompleteness makes the notion of optimal security design particularly relevant and can be driven by frictions such as transaction costs, marketing costs, or imperfect pledgeability of payoffs. Market incompleteness causes agents to value assets differently at the margin, with important equilibrium and welfare implications. But how exactly does market incompleteness create incentives to innovate?

3.2. Market incompleteness and incentives to innovate

There are many reasons behind agents' incentives to innovate. Tufano (2003) provides an overview of the literature on financial innovation, making a distinction between innovation driven by market incompleteness, information asymmetries, various costs faced by agents, taxes and regulation, globalization and technological shocks. Given that the focus of this section is on the interaction between security and market design, we restrict the scope of the review to innovations driven by market incompleteness.

3.2.1. Risk management

An important driver behind the development of innovative derivative securities is the need to address incompleteness in the traded-securities market that enable risk sharing. Derivatives are an important and broad class of security design innovations that allow managing risk and hedging against various contingencies. Unlike traditional securities, such as stocks and bonds, which can be conceptualized as contracts that grant rights to cash flows generated by real assets, investment projects or which represent ownership claims in corporations, derivative securities merely entitle the owner to cash flows that are a function of the performance of an underlying asset, index or event. Another way to think about derivatives is agreements that certain payoffs be made under certain conditions rather than ownership claims. Although we will center our discussion around derivatives, we must note that exchange traded funds (ETFs) represent another important financial innovation that has grown in popularity since the mid-1990s. ETFs are conceptually similar to derivatives in that they entitle the owner to cash flows that track a diversified portfolio of underlying assets or an index. They are traded on exchanges just like individual stocks, thus providing investors with a low-cost, highly liquid, diversified, and easily accessible investment vehicle. We refer readers interested in the workings of ETFs to the literature review by Ben-David et al. (2017).[8]

Derivatives markets started gaining prominence in 1970s and have since grown exponentially. The Bank for International Settlements estimates the total size of OTC derivative markets, measured in terms of total notional outstanding, to be $632.2 trillion as of 2022.[9] The increase in magnitude has been matched by a proliferation of products, ranging from those that hedge against traditional financial market risks such as interest rate, foreign exchange rate or credit risk, to those hedging against specialized or industry-specific risks such as commodity, weather or mortality risks. In terms of derivative security designs, futures and options are perhaps the most commonly known and used types of derivatives. Futures are agreements to exchange an underlying asset at a predetermined price and a specified future date. On the other hand,

[7] Note that whereas most of the papers discussed in Section 2 tend to focus on optimal security choice while taking security design as given, in this section we focus on the question of how securities should be optimally designed in the face of market frictions.

[8] Another reference, which focuses on the systemic risks related to ETFs is Bhattacharya and O'Hara (2020).

[9] BIS OTC Derivatives Statistics www.bis.org/statistics/derstats.htm

options give the holder the right, but not the obligation, to buy or sell an underlying asset at a specified price, known as the strike price, on or before a certain date known as the expiration date. Given the variety and complexity of securities on global derivative markets, any review of security designs attempted here is bound to be incomplete and is beyond the scope of this paper; the reader is referred to Hull (2014), Jarrow and Chatterjea (2013) or Bellalah (2008) for comprehensive overviews of derivative markets. Instead, we aim to discuss the incentives behind financial and non-financial institutions' issuance and use of derivatives.

Financial intermediaries (FIs) make markets in derivatives. They also take positions in derivatives to hedge against various risks, manage their balance sheets, and speculate on market movements. The biggest category of derivatives, in terms of total notional value, is represented by interest rate derivatives. In terms of designs, swaps are one of the most popular interest rate derivatives used by FIs. Interest rate swaps allow two parties to exchange fixed-rate and floating-rate cash flows based on a notional principal amount over a specific period. Interest rate collars are another derivative security that is widely used by FIs. This security design involves the simultaneous use of calls and puts on interest rates, which allows creating a "collar" or range within which the interest rate is constrained. Purnanandam (2003) provides an empirical analysis of banks' use of derivatives for risk management.

What drives FIs to innovate through the introduction of derivatives? And what are the welfare implications of such innovation? Market incompleteness creates incentives for agents to innovate, as value typically accrues to the innovators. Several early papers have examined the dependence of security design on the way in which value accrues to innovators and the characteristics of the market in which they innovate. 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 weighed 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. 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.

Although FIs are the makers and main users of derivatives, non-financial firms also use derivatives for a variety of purposes. What drives non-financial corporations' use of derivatives? Using corporate reports for 7300 firms from 48 countries, Bartram et al. (2009) found that 60 % of these firms used derivatives. The most frequently used were foreign exchange derivatives, followed by interest rate derivatives and commodity derivatives. The firms that used foreign currency derivatives had foreign currency transactions, and firms that used interest rate derivatives had higher leverage. Furthermore, the use of derivatives for hedging was found to be more prevalent among firms with higher leverage and lower balance sheet liquidity. There is also evidence that firms use derivatives to minimize earnings volatility (Bodnar et al., 1995), to reduce the present value of their tax liabilities (Graham and Rogers, 2002), and that the nature of management compensation also affects firms' hedging behavior (Rogers, 2002). From a theoretical perspective, Chowdhry et al. (2002) propose a model that rationalizes the issuance of currency swaps by multinational firms. The fact that investors face uncertain costs of reorganizing foreign assets in case of bankruptcy prompts them to value foreign assets at their average value, thus imposing an adverse selection penalty on superior firms with low reorganization cost. Such penalty can be minimized by designing a security that allocates all cash flows in bankruptcy to investors with smaller adverse selection cost given the exchange rate. Currency swaps can implement this sharing rule and allow the priorities of claims in bankruptcy to change depending on the exchange rate.

3.2.2. Speculation and welfare

Given that markets are incomplete, one might assume that innovation that gives participants greater freedom of choice and expands financial opportunities, should enhance social welfare and benefit all agents. Elul (1995) studies the welfare effects of financial innovation in incomplete markets and finds that the addition of a new security may have almost arbitrary effects on agents' utilities and can make all agents strictly worse off. Therefore, the introduction of derivatives is not generally beneficial. But should it not be the case that the introduction of derivatives that improve risk sharing and have positive implications from a risk management perspective should be beneficial? To the extent that such derivatives also create scope for speculation, this is not clear. 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.

By enabling the production and aggregation of information better and faster, derivative markets can make the underlying markets more efficient. As pointed out by Stulz (2004), derivative markets produce information. For example, information about long-term interest rates can be obtained from swaps, which are more liquid and active than bond markets. Derivative markets also enable investors to act on information that might otherwise be too expensive to utilize. For example, investors can use put options to leverage adverse information about stock prices instead of short-selling stocks they do not own by borrowing them. This latter example should also make it clear that derivatives make it easier to build speculative positions and can disrupt markets. They also allow decoupling economic interests from governance, which has implications for social welfare. Barry et al. (2013) note that derivatives allow investors to hold economic interests in a corporation without owning voting rights, or vice versa, which creates empty voters (voting rights in a corporation exceed the economic interests of investors) and hidden owners (economic interests exceed investors' voting rights). When financial markets are opaque, empty voting and hidden ownership can render financial markets unpredictable, unstable, and inefficient, but the opposite happens if markets are transparent.

An important class of derivative securities, which provides a stark illustration of the separation between economic interests and control rights are credit default swaps (CDS). CDSs are insurance-type contracts that offer buyers protection against default by a borrower. Specifically, a CDS is written on the debt of a reference entity and makes payments that are contingent on the occurrence of a contractually defined credit event, such as failure to pay, bankruptcy, or restructuring. CDSs give rise to an empty credit problem whereby a debt holder can obtain insurance against default but otherwise retains control rights in and outside bankruptcy (Bolton and Oehmke, 2011).[10] Unlike other derivatives, that do not affect the fundamentals of the underlying assets, CDSs may have real effects, and evidence suggests that they indeed affect firm behavior,

[10] Interventions by CDS buyers and sellers in the restructuring of a distressed firm and can, under certain assumptions, solve the empty creditor problem and firm value reaches first-best (Danis and Gamba, 2023).

the economic incentives of financial intermediaries and the creditor-borrower relationship. The introduction of CDS has been shown to affect firm values and the real decisions of the reference firms, including those regarding leverage, cash holdings, investment, and the riskiness of the firms' investments (Subrahmanyam et al., 2017; Danis and Gamba, 2018; Bartram et al., 2019). Although CDS trading allows firms to borrow more, potentially at lower interest rates, longer maturities, and with looser covenants (see Augustin et al. (2014) and references therein), borrowers could very well be negatively affected by such availability of additional financing, and evidence suggests that the introduction of CDS trading increases the credit and bankruptcy risk of the reference firms (Subrahmanyam et al., 2014). Furthermore, Ashcraft and Santos (2009) find no evidence that CDS trading lowers the cost of debt financing for the average borrower in corporate bond and syndicated loan markets; instead, borrowing costs increase for high-risk borrowers, while they decrease for low-risk borrowers. Augustin et al. (2014, 2016) provide excellent CDS surveys, which also point to open research questions in this area.

Increased market efficiency, the fact that markets incorporate and transmit information more efficiently, is not always beneficial though and has been argued to increase volatility and potentially lead to market crashes. Additionally, the information transmission role of prices might have an adverse impact on risk-sharing, as agents update their risk perceptions based on the new information. Thus, it is unclear whether introducing new securities is always desirable, or if agents might prefer an incomplete set. 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 efficiency of markets in aggregating and transmitting information depends on the financial structure and the number of tradeable assets. 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, the revelation of information reduces risk-sharing opportunities because trading risks that have been resolved is impossible, giving rise to the so-called Hirshleifer effect. 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.

3.2.3. Redundant securities

The introduction of derivatives does not only create opportunities for speculation, but it also raises concerns about their redundancy. The idea behind the redundancy argument for derivatives is that they can be replicated using a combination of existing securities, and thus do not offer any unique payoffs that cannot be achieved through a portfolio of existing simpler assets. So, what justifies the existence of seemingly redundant securities? Gorton and Pennacchi (1993) use information frictions to rationalize the existence of composite securities with values that are functions of the cash flows or values of other assets, and which are seemingly redundant. Although these securities might seem redundant when investors can costlessly 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 co-exist when uninformed investors are differentiated into clienteles with respect to non-tradeable endowment shocks, and the size of each such clientele is small. Frictions other than informational ones can play a role in security design, as highlighted by Shen et al. (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 structure is important because it has price impact implications. Price impact, in turn, creates a motive for creating an alternative trading venue or introducing a new financial product, and can make derivatives non-redundant. 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 in this paper is that demands are not contingent and most assets clear independently rather than jointly. 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.

3.3. Market structure and security design interactions

Market segmentation motivates the introduction of new securities. Insofar as the introduction of a new security amounts to the creation of a new market, it also changes market structure. Thus, there is an endogenous relationship between market and security design, which we discuss in this section. Below, we discuss how innovation is motivated by market segmentation, and the implications of innovations that refer not only to the introduction of novel security designs but also to the integration of segmented markets.

Segmented markets create incentives to innovate in the presence of strategic arbitrageurs. Rahi and Zigrand (2009) study strategic financial innovation in segmented markets, where segmentation is conceived as limited investor participation. 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. Given that the integration of segmented markets can be conceived as a form of innovation, what are the market structure implications of financial innovations consisting of both the introduction of new assets as well as the integration of segmented markets? Acharya and Bisin (2005) study precisely this question and characterize the ensuing 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, and the structure of financial assets is optimal if all assets are designed to maximize risk-sharing.

The securities designed by financial intermediaries are not immune to the market structure in which trade occurs. Recognizing this is important and raises several questions. How does security design depend on market structure? How are market structure and security design jointly determined? Babus and Hachem (2021) address these questions, studying in particular the role played by market power in shaping the relationship between security design and market structure. 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. Investors choose to trade in thinner, more fragmented markets to obtain safer securities.

While most papers approach the question of security design from the perspective of it being a response to market imperfections, an equally important question is: How can securities and markets be designed to mitigate market imperfections? This question is studied by Biais and Mariotti (2005), who focus 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.

In sum, the notion of optimal security design is relevant only in incomplete markets, which can be a result of frictions such as transaction costs, marketing costs and imperfect pledgeability of cash flows. Market incompleteness creates incentives for agents to innovate. An important driver of innovation is the desire to introduce securities that improve risk sharing and have positive implications from a risk management perspective, such as derivatives. However, the introduction of such securities is not always beneficial because they also create opportunities for speculation. Concerns have also been raised about their redundancy, but the existence of seemingly redundant securities can be rationalized through information frictions, collateral frictions and price impact. The introduction of new securities can make markets more efficient through the production and incorporation of information, but increased market efficiency does not necessarily improve welfare, as it can increase market instability and it can also have an adverse impact on risk-sharing through the information transmission role of prices. Therefore, it is not clear what are the full implications of creating markets in new securities. This has the effect of changing market structure, which in turn motivates the introduction of other new securities. The endogenous relationship between market and security design has yet to be fully understood.

The derivatives market has often been a battleground for debates regarding whether innovation contributes positively or negatively to social welfare. While theoretical research has provided useful insights into these implications, it is challenging in practice to assess welfare and the impact of specific innovations. This is due to the inability to directly measure social welfare and benchmark the observed outcomes against those never observed. Additionally, establishing the scope of a specific innovation can be quite complex, as successful innovations tend to spark subsequent ones. It will be interesting to see how security design, market design, and their interaction is going to evolve in response to the changes brought about by technological innovation, such as automation, securities digitalization, and smart contracts to name a few. We will discuss such innovations in more detail in Section 6.

4. Financial intermediation

Financial intermediaries provide essential liquidity in maturity transformation services to the economy and issue contracts that serve economic agents with varying preferences for state-contingent payoffs. We will not cover the large literature going back to Diamond and Dybvig (1983) dealing with the design of securities issued by FIs, nor their optimal capital structure,[11] but merely note that the incompleteness of the key contract issued by FIs, the demand deposit, makes them inherently unstable and subject to runs, which can lead to financial crises and contagion (Allen and Gale, 1998, 2000). The low level of equity financing that characterizes the capital structure of FIs further amplifies their fragility, as relatively small losses are amplified by leverage and can easily deplete their capital buffers.

In this section we focus on issues that have gained prominence in the lead up and following the financial crisis of 2007–2008. Specifically, we start by discussing issues related to the creation of financial securities through securitization, followed by security design applications aimed at restoring the capital of troubled financial institutions through contingent capital.

4.1. 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 than 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. Through the process of securitization, 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).[12] 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.

4.1.1. Securitization and agency problems

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 the originating banks' balance sheet.[13] 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-

[11] Some bank capital structure references include Gale (2004), Allen, Carletti and Marquez (2015), Gale and Yorulmazer (2017), Gale, Gamba and Lucchetta (2017), Admati and Hellwig (2013), DeAngelo and Stulz (2015), Gale and Gottardi (2020).

[12] 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.

[13] In addition to secondary market selling, loan syndication has also contributed to moving away from the traditional originate-to-hold model to the originate-to-distribute model of lending (Bord and Santos, 2012).

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 and/or securitized loans and 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 et al. (2010) find that mortgage 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 et al. (2011) provide evidence that is consistent with 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 et al. (2009) examine federally guaranteed mortgages, whose main risk to investors is that 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 et al. (2012) provided evidence consistent with the argument that adverse selection issues are less severe in the case of corporate loan securitizations, because these securitized loans are fractions of syndicated loans, and the mechanisms used to align incentives in a lending syndicate likely mitigate adverse selection in the choice of collateral.[14] However, there is also evidence that securitization leads to poor-quality corporate loans. Specifically, Bord and Santos (2015) find that syndicated loans sold to collateralized loan obligations (CLOs) underperform relative to matched unsecuritized loans originated by the same bank, in line with the findings from the mortgage literature (Keys et al., 2010; Purnanandam, 2011).

4.1.2. Pooling and tranching

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 split and allocate the cash flows generated by the pool of assets to various categories of investors. The latter can also be thought of as the SPV's capital structure choice. In this subsection, we discuss the benefits or advantages of pooling, and of optimally combining pooling and tranching. An in-depth discussion of tranching, from the perspective of securities creation, is deferred to the next section where we also discuss its relation to signaling, moral hazard and regulation.

Pooling, also referred to as 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 lemon-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. Given the impact that pooling can have on market liquidity through information revelation, how do the benefits of pooling depend on market structure and market power in particular? Glode et al. (2022) examine optimal pooling in OTC markets, which 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.

Moving away from aggregate market outcomes, what are the drivers behind pooling from an asset seller's perspective? What drives the choice between selling assets separately or pooling them together as a bundle? DeMarzo (2005) analyses the interaction between pooling and tranching, and highlights that pooling erodes any informational advantage that privately informed sellers might have. 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, what are the forces or incentives 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. Garmaise (2001) studies the security design problem of a cash-constrained firm facing investors that agree to disagree. 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. Another departure from rational expectations is considered by Noe et al. (2006), who 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

[14] For a review of the role of lending syndicates in securitization see Bord and Santos (2012). For the role of bank syndicates in providing liquidity see Santos and Viswanathan (2024) and references therein.

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. But a model which allows investors to learn how to price securities through experience can rationalize the optimal bundling and splitting of cash flows.

4.1.3. Tranching and the creation of new securities

Tranching involves partitioning and selling the cash flows generated by underlying pools of assets to different classes of investors. The simplest design for splitting the cash flows generated by an underlying pool of assets takes the form of so-called "pass-through" securities and involves paying all cash flows generated by the pool on a pro-rata basis. Most often the asset pool is represented by mortgage loans, so the cash flows distributed include interest, principal and repayments net of the fees. However, by creating tranches which divide cash flows by risk, time to maturity, or other group characteristics, issuers can create securities that appeal to investors with different needs and risk appetites, and which thus have a greater marketability.

One of the most widely used tranching designs is according to credit risk. This 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. However, other designs are customarily implemented to create tranches that appeal to investors with different maturity, prepayment risk and duration preferences. Such an example is interest-only (IO) and principal-only (PO) mortgage-backed strips, which involve separating the cash flows from an underlying pool of mortgages into a tranche that pays only the interest payments from the mortgages, and another one which pays only the principal payments. The PO component has a much longer duration than the underlying mortgage pool, while the IO component typically has a negative duration (Marcus and Kling, 1987). This structure thus caters to investors with different duration preferences. For an overview of MBS markets which also discusses different security design examples see Fuster et al. (2023).

Creating tranches according to credit risk results in a senior/subordinated structure, where principal payments are directed first to the senior tranches, while lower-ranked junior or subordinated tranches, also referred to as mezzanine tranches, initially receive only coupon payments. The lowest-ranked tranche, also referred to as the equity tranche, is the first to absorb credit losses and therefore has the highest risk. Tranching according to credit risk amounts to creating securities that are more or less sensitive to seller's private information. The senior tranches can be thought of as being equivalent to debt, while the subordinated or junior tranches are conceptually similar to equity. In other words, tranching by credit risk enables decomposing asset cash flows into an 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. So, what is the role played by information asymmetries in tranching? Specifically, what is the role played by adverse selection arising from the potential informational advantage of the asset-backed security sellers?

Gorton and Pennacchi (1990) approach security design from the perspective of creating assets that uninformed agents can trade without suffering losses to better-informed agents. Splitting the cash flows of underlying risky assets and creating information-insensitive securities with a riskless return arises endogenously, as a way to protect relatively uninformed agents by limiting trading losses associated with information asymmetries. In contrast, Boot and Thakor (1993) approach security design from the perspective of security designers who want to maximize revenues. When investors are asymmetrically informed about asset values, a value maximizing liquidation strategy is to split cash flows into informationally sensitive and insensitive securities and sell multiple financial claims to partitioned asset cash flows rather than a single claim to total cash flows. The presence of informed and uninformed investors in the market, who choose to hold each of the respective categories, provides a rationale for cash flow partitioning as this makes informed trade more profitable. Thus, the two papers provide different rationales for tranching. The aim of security design in Gorton and Pennacchi (1990) is to create an information-insensitive security to protect uninformed investors, but in Boot and Thakor (1993) is to create a security with maximum information sensitivity to maximize the revenue of the issuer.[15] Evidence that tranching is made with a view to suit particular investor tastes for the information-sensitive tranches is provided by Firla-Cuchra and Jenkinson (2005). Using a proprietary database of over 5000 separate tranches of European securitizations raising a total of $1 trillion between 1987 and 2003, the authors find support for asymmetric information and market segmentation explanations for tranching and show that tranching can increase prices for the issue as a whole. They document a strong relationship between issue size and the creation of tranches within a rating class, rather than the creation of additional tranches with distinct ratings, which points to the importance of market segmentation and/or downward sloping demand curve effects. Using a measure of information-sensitivity of different asset types based on the variance of observed launch spreads, they find that information asymmetry has a significant impact on the number and type of observed tranches, especially when it comes to the creation of additional tranches with distinct ratings.

What are the implications of deeper tranching or, in other words, creating a high number of tranches that cater to diverse investors? Empirical evidence points to coordination frictions between investors in deeply tranched RMBS loan pools. Korgaonkar (2023) examines RMBS servicer decisions on 1.5 million delinquent loans and finds that an interquartile increase in tranching reduces mortgage servicers' probability of loan renegotiation by 14 % relative to the mean. The effects of tranching are driven by both diversity in tranche seniorities and the number of tranches and are concentrated in mortgages with greater ambiguity surrounding the loan value maximizing action. This is interpreted as evidence that deeper tranching creates coordination frictions that impede the monitoring of servicing agents, and eventually contributes to larger losses on delinquent loans.

Differences in the degree of informativeness of investors also play an important role in tranching by creating motives for strategic trading and through anticipated secondary market liquidity effects, which not only influence tranche design but also impact the value of the underlying pool of assets. So, how does trading affect tranching and the value of the underlying portfolio? Friewald et al. (2016) study optimal tranching in relation to trading and associated adverse selection issues. 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 model predictions are verified empirically. The authors provide evidence that liquidity increases monotonically in seniority, and there is a positive relationship between the numerical priority position of the most junior traded claim in a pool

[15] Going beyond securitization and tranching, these papers rationalize the issuance of high information sensitivity securities like options, as well as the issuance of information-insensitive securities such as deposits by banks. These two viewpoints can be seen as complementary rather than contradictory, as evidence by the fact that banks issue both types of securities and highlight the fact that securities can and do serve a range of purposes, from maximizing revenue for issuers to providing stability and protection for investors.

and that claim's illiquidity.

The idea that trading considerations matter for tranching is also explored by DeMarzo et al. (2021), who 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. The optimality of tranching has also been rationalized in terms of non-exclusive markets, in the sense that the seller cannot commit to accept contracts from only one buyer. Asriyan and Vanasco (2023) study security design in a setup in which buyers post menus of contracts to screen a privately informed seller, and markets are non-exclusive. 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.

With most of the literature at the intersection of tranching and security design focusing on the allocation of cash flows, the allocation of control rights to various tranches is a relatively less researched topic. The main question when it comes to governance issues related to securitization is: 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. The paper considers governance issues related to debt renegotiation and in particular the issue of which tranche should control liquidation and renegotiation, and suggests that 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 trade-off 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 when subordinate security holders have direct 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, and the value-enhancing properties of specific governance mechanism are isolated empirically.

4.1.3.1. Tranching and signaling. When originators are privately informed, the choice of how to split the cash flows as well as which tranche to retain effectively signals sellers' private information. How exactly can tranching be used to produce information? What are the incentives behind and implications of using tranching for signaling purposes? 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 who 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 tranche retention choice.

Starting from the premise that a privately informed issuer's choice of what security to issue signals something about quality, Daley et al. (2023) study the implications of an improved informational environment for the form of security designed and the amount of inefficient retention of cash flows. They focus in particular on so-called scrutiny, which can take the form of either credit ratings, analyst reports, or mandatory disclosures. Scrutiny 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 like equity but otherwise, the optimal security design is a standard debt contract. Daley et al. (2020) explore the implications of enhancing the availability of public information, through the introduction of credit ratings, for the use of retention as a signal of quality. The introduction of ratings endogenously shifts the economy from a signaling equilibrium in which banks inefficiently retain loans to signal quality, towards an originate-to-distribute equilibrium with zero retention and inefficiently low lending standards. Ratings increase overall efficiency when the reduction in costly retention is high enough to compensate for the origination of some negative net present value loans. 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.

But is there empirical evidence on tranching being used as a signaling device? Begley and Purnanandam (2017) provide evidence from the residential mortgage-backed security (RMBS) market that the equity tranche is used as a signal of the unobserved quality of opaque pools. The authors document that deals with a higher level of equity tranche have a significantly lower delinquency rate conditional on observable loan characteristics, and this effect is concentrated within pools with a higher likelihood of asymmetric information between deal sponsors and potential buyers. Further, investors responded to such signaling by paying higher prices for deals backed by higher equity tranches. Taken together, this evidence is consistent with the idea that the level of the equity tranche conveys the sponsor's private information, particularly in deals with severe adverse selection concerns, and points to tranching being used to address a lemon's problem. However, there is also evidence that tranching is made with a view to cater to investors with preferences for certain types of cash flows or securities. Balthrop et al. (2020) document that the increase in tranching preceding the 2007–2008 financial crisis was in part a response to investors demand for securities with apparent good credit quality. They document a 1.2 % increase in the issuance of long-term Collateralized Mortgage Obligations (CMOs) with low prepayment risk in response to 1 % increase in excess demand for long-term U.S. Treasury bonds. This substitution effect is only present for CMOs with characteristics similar to long-term government bonds but not for short duration or high prepayment sensitivity.

4.1.3.2. Tranching and regulation. Given that through tranching and retention choices issuers effectively choose how much of the potential losses they will internalize, tranching and retention can be used to mitigate moral hazard. 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 vertical slice (which is a share of the entire portfolio), 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 et al. (2009). They provide evidence that default rates were overall higher for loans originated by regulated banks than for less-regulated independent brokers, suggesting that regulatory oversight alone is not the solution. The findings point to a

role for specific regulations requiring skin in the game for brokers in order to mitigate moral hazard.

Insofar as retention choices can be used to mitigate moral hazard issues, can mandating appropriately designed retention schemes 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.

Rather than focusing on skin in the game provisions as a way to mitigate moral hazard, Hartman-Glaser et al. (2012) highlight that the timing of payments from mortgage securitization can be a key incentive mechanism. This paper analyses a dynamic setting in which a mortgage underwriter needs to exert costly hidden effort to screen borrowers and can sell loans to investors. By selling mortgages, rather than holding them in her portfolio, the mortgage underwriter can exploit new investment opportunities. Information about the performance of the underlying pool of loans is revealed over time and although investors do not observe the actions of the underwriter, the timing of mortgage defaults is publicly observable and contractible. The optimal contract between a mortgage underwriter and secondary-market investors is about when the underwriter is paid, rather than what piece of the underlying assets it retains and takes a simple form. Specifically, investors receive the entire pool of mortgages at time zero and make a single lump sum transfer to the underwriter after a waiting period provided no default occurs. If a single default occurs during the waiting period, investors keep the mortgages, but no payments are made to the underwriter. This optimal design of mortgage-backed securities is closely approximated by a "first loss piece" contract which involves the underwriter retaining the junior tranche and receiving the proceeds from the sale of the senior tranche.

Securitization has been pointed at as a key factor leading up to the 2007–2008 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 et al. (2008) examine the determinants of the size of the equity tranche retained by the sponsor and find 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 (2013) 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 2001 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.

Although securitization has been discussed as a factor that played an important role in the lead up to the crisis, Ozdenoren et al. (2018) 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.

In sum, there is a large body of literature that seeks to explain observed securitization structures, the optimality of pooling and tranching, as well as the ways in which new securities can be created through tranching. Tranching allows dividing the cash flows generated by an underlying pool of assets by credit risk, prepayment risk, time to maturity, duration and other group characteristics, thus creating securities that appeal to investors with different preferences and which have a higher marketability. Tranches can also be optimally designed to provide appropriate incentives, mitigate adverse selection and moral hazard, and in fact mandating appropriately designed retention schemes has been proposed as a regulatory tool. There is also evidence that tranche retention choices can be used to signal sellers' private information and the quality of the underlying pools.

It is still unclear if securitization is welfare enhancing. Securitization of mortgage loans has contributed to increasing home ownership, but it also contributed to fueling a housing pricing boom that culminated with the Global Financial Crisis of 2007–2008. So, it is not entirely clear that the welfare implications of this are positive, especially if one is willing to question the idea that home ownership is welfare enhancing. In terms of future research questions, it would be interesting to study how securitization structures have evolved over time, and what are the potential next innovations in this area. For instance, how shall we think about the securitization of new types of assets such as art, NFTs or digital assets more generally? What are the challenges and implications of such securitizations? More importantly, we are observing a shift in the economic paradigm from a reliance on real capital and tangible assets, to a data-driven model in which intangible assets, like data and intellectual property, are central to value creation and economic activity. What role can securitization play in the data economy? Can it be used to spur investment in intangible and intellectual capital? How can technology, especially blockchain and the improved traceability of underlying assets that it enables, influence the securitization processes? Can securitization be used to further ESG goals or is it more likely to lay fertile ground for greenwashing?

4.2. *Contingent capital*

The capital structure of financial intermediaries (FIs), and in particular their low level of equity financing, is the subject of an extensive academic literature as well as numerous regulatory debates. FIs have a considerably lower level of equity financing, or so-called capital, compared to other types of corporations. This 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 Great Financial Crisis of 2007–2008. In addition to increased capital requirements, which provide 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 upon the occurrence of a pre-specified trigger event, and represent 55 % of the current issuances (Avdjiev et al., 2020). The remaining issuances consist of CoCos that convert into equity when triggered. 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 relative to 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 given by the contemporaneous share market price. What is the rationale behind including all these features in the design of contingent convertible securities? What frictions are they meant to overcome and/or what risks are they supposed to mitigate? The exposition of this section will be structured around the various security features that have been proposed in the literature and the issues that they are meant to address. In other words, this section will focus on clarifying the rationale behind considering variations of a security features such as the conditions triggering conversion, the cash flow and control rights associated with the instruments to which conversion will take place, or the conversion rates.

4.2.1. *Conversion-related features*

We start by discussing papers that have mainly tackled questions related to what should be the securities that contingent capital securities are converted to and what the conversion ratio or price should be. Although contingent capital securities offer the advantage of allowing issuing banks to recapitalize and avoid bankruptcy, their issuance 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. Risk-taking incentives can be addressed by making equity holders internalize the consequences of their actions. This raises the question: how can contingent capital securities be designed to achieve this? 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 an FI'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 an FI should the need arise and expose RCD investors to very limited credit risk under plausible conditions. However, even when they are designed to dilute equity holders rather than bond holders, the two classes of investors are likely to have different risk-preferences and conversion to common shares would not account for such differences. Coffee (2010) proposes a contingent capital security design whose main purpose is to create a countervailing voting constituency to offset the voting power of risk-tolerant common equity holders. This would involve conversion to a senior, non-convertible preferred stock with cumulative dividends and significant voting rights. Additionally, 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.

The fact that conversion ratios are typically set to dilute equity holders generates incentives to preemptively raise equity capital to avoid triggering conversion, making dynamic considerations important. Himmelberg and Tsyplakov (2020) propose a dynamic capital structure model to examine the optimal design and ex-ante incentive effects of issuing CoCos. 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 generates windfall gains for equity holders.

Another issue related to the inclusion of CoCos in banks' capital structure is that they can potentially increase executives' incentives to increase risk. Can bankers' compensation be designed to reduce the risk-shifting incentives brought about by the issuance of CoCos? Hilscher et al. (2022) investigate not only how CoCos should be designed to reduce risk-shifting incentives, but also explore the role of executive compensation designs. They show that 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.

In principle, conversion should be designed to avoid wealth transfer from bondholders to equity holders, but is this reflected in practice? Berg and Kaserer (2015) first show theoretically that when conversion transfers wealth from CoCo bond holders to equity holders, the latter's incentives to increase the riskiness of assets increase, and 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. 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. So although in theory CoCos should be designed to dilute rather than benefit equity holders this is not the case in practice.

Gamba et al. (2022) rationalize why dilutive CoCos are rarely, if ever, observed in practice and study the implications of non-dilutive designs for FI's risk-taking incentives. Using an agency model of two subsequent moral hazard problems, they show that non-dilutive conversions are particularly powerful in preventing gambling for resurrection. Moral hazard can occur at a first stage, when FIs choose the risk of their lending activities and at a second stage when, knowing privately that they are approaching the trigger event, FIs can gamble for resurrection. The authors show that non-dilutive features are a necessary evil, in that a capital-constrained FI may have to use non-dilutive CoCos to boost its financing capacity, as well as mitigate ex-post risk-shifting, at the cost of allowing for a degree of ex-ante risk-taking.

4.2.2. *Trigger-related features*

To address the debt overhang problem related to equity holders' reluctance to raise capital through the issuance of equity at low market

prices, contingent convertible security designs often have automatic triggers. These are a set of conditions which, when met, automatically trigger conversion to the agreed-upon security at the agreed-upon conversion ratio or price. Despite advantages related to timely reflection of the issuer's financial condition, triggers based on market prices may create incentives to manipulate the stock market. For instance, speculators can purchase an issuing FI'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, as it fails to take into account market signals and conditions. Pennacchi et al. (2014) propose a security design that is meant to be robust to such market manipulation, the 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 related to market-based conversion triggers are highlighted by Albul et al. (2015), who develop a valuation model for CoCo bonds with market-based triggers and derive conditions under which equilibrium is unique. Although CoCo 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. Empirical evidence that debt overhang affects a financial institution's willingness to issue CoCos is provided by Goncharenko et al. (2021). 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.

Market-based triggers not only create manipulation issues, but theoretically defining an internally consistent market-based trigger can be problematic. Sundaresan and Wang (2015) raise concerns that contingent capital proposals generally do not 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.

McDonald (2013) discusses market-based triggers, focusing in particular on the benefits of single or dual price trigger specifications. 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 other 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.

Pennacchi (2019) develops a structural credit risk model of a bank that issues short-term deposits, equity, and fixed- or floating-coupon contingent capital debt, and which has a market-based trigger. 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 had 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.

A trigger variation based on accounting rather than market values is studied by Glasserman and Nouri (2012). Specifically, they develop a model to value contingent capital with a capital-ratio trigger based on book values, which approximates the regulatory ratios used in practice to determine capital requirements for banks. The conversion process they consider is partial and ongoing, which means that every time the bank's capital ratio reaches the minimum threshold, just enough debt is converted to equity every time the conversion threshold is reached and until the contingent capital is depleted. Contingent capital prices are found to be highly sensitive to model inputs that are not directly observable, and which are difficult to estimate, which coupled with the overall complexity of products lead the authors to conclude that there can be considerable obstacles to the widespread issuance and adoption of contingent convertible bonds.

4.2.3. Implementation issues

The promise of contingent convertible capital securities as a "bail-in" solution has been the subject of considerable theoretical analysis and debate, but relatively little is known about their effects in practice. What is the evidence regarding their implementation? Avdjiev et al. (2020) undertake the first comprehensive empirical analysis of bank CoCo issues, a market segment that between 2009 and 2015 consisted of over 730 instruments totaling $521 billion. The issuances of principal write-down CoCos, which replenish the issuing FI's balance sheet by writing down the principal amount, was relatively higher than so-called mandatory conversion CoCos, which increase capital by converting into common equity at a predefined conversion rate. 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 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.

Although the literature has explored many security design variations, regulatory-compliant CoCo implementations have triggers based on a book value capital ratio. Given the staleness of book or accounting values, this raises the question of whether CoCos will actually convert or be written down while the bank is still solvent. Fiordelisi et al. (2020) point out that in the first test case, represented by Spain's Banco Popular, CoCos never converted before its bank failed. They conduct a comprehensive empirical analysis using 2011 to 2017 data on European banks and ask the question of whether CoCos perceived to be truly "going-concern" capital, meaning that CoCos will trigger before the bank is insolvent. They present evidence that is consistent with investors perceiving only equity conversion CoCos, but not principal write-down CoCos, as going-concern capital. Exploiting regulatory actions taken in 2016 and 2017, the paper documents a reduced yield spread between a bank's CoCo and its subordinated debt, which indicates a diminished investor belief that even equity conversion CoCos are going-concern capital.

Empirical evidence suggests that the type of contingent capital design that has been chosen by banks is not one that favors debt holders (Berg and Kaserer, 2015; Goncharenko et al., 2021). But even if the design of CoCos issued might have the (undesirable) feature of making equity holders the sole or main beneficiaries of conversion, can their issuance still be beneficial from a welfare perspective? CoCos can be designed to effectively implement countercyclical capital buffers and can thus be used as a macroprudential tool. Zeng (2014) derives optimal countercyclical bank capital requirements and shows that they can be implemented using CoCo instruments. In an environment with macroeconomic uncertainty, CoCo bonds emerge as part of the implementation of the optimal contingent capital structure of a bank with risk-shifting incentives and private information. Bolton and Samama (2012) also discuss the implementation of countercyclical capital buffers using CoCos. This involves doing away with automatic triggers altogether and designing the CoCos as reverse convertible bonds granting the issuer the option to convert the bond into equity. This design for contingent capital, called capital access bonds, implies that issuers would only convert when the put option embedded in the CoCo is in the money, which is more likely to be the case in recessions or in a financial crisis. By exercising the option, the issuer can effectively recapitalize the bank at more favorable terms than those available in the market. A CoCo structured as a reverse convertible bond would be equivalent to giving the issuer a commitment to augment its equity capital at will, and at favorable terms, in recessions, thus implementing a form of countercyclical equity buffer. Rather than being a substitute for bankruptcy, this security would act as a capital line commitment to banks.

Vallée (2019) shows that European banks that had issued hybrid debt before the crisis took advantage of the option to convert the debt issues in the middle of the crisis of 2007–2008, which enabled them to partially recapitalize their stressed balance sheets. Specifically, this paper examines liability management exercises which bear regulatory capital effects comparable to contingent capital instruments. 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 was positive and the created value mainly accrued to debt holders.

However, Illueca et al. (2022) provide empirical evidence on the unintended effect of implementing countercyclical prudential buffers in terms of increasing bank risk-taking. Specifically, they examine the implementation by Spain's central bank in July 2000 of a prudential buffer in the form of dynamic loan loss provisioning (DLLP), which required banks to include an additional component related to historical losses, beyond the loan loss provisioning associated with specific borrower risk. Although this was effective in reducing the pro-cyclicality of both credit and leverage by dampening the boom and mitigating the crunch during the crisis, it led to banks extending loans to riskier borrowers with lower accounting quality.

To conclude, 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 (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.

A benefit or advantage of bail-in instruments such as contingent capital is avoiding that troubled FIs are bailed out by the government. Government bailouts have the undesirable effect of increasing moral hazard and leading to excessive risk taking, leverage and correlated asset choices (e.g., Farhi and Tirole, 2012; Greenbaum, Thakor and Boot, 2019). An extensive prudential regulation machinery, combined with normal regulatory supervisions, is already in place to deal with the specter of moral-hazard-induced failures of institutions that anticipate being bailed out. Whereas issues related to the optimal design of government intervention (Philippon and Skreta, 2012; Tirole, 2012; Bianchi, 2016; Berger et al., 2020; Song and Thakor, 2023) are beyond the scope of our review, we want to discuss the design of an instrument used by the U.S. Treasury to assist troubled banks during the 2007–2008 crisis. Under the Capital Purchase Program (CPP) authorized by the TARP legislation, the Treasury infused equity capital into over 700 banks using dividend-paying preferred stock (subordinated debt), which gave the government the ability to appoint independent directors on the board of an assisted bank if it missed six dividend (coupon) payments. These securities, which effectively made governance contingent on repayment, were designed to limit ex-post moral hazard and thereby lessen the distortions associated with the government assistance. Indeed, Mücke et al. (2023) provide evidence that this security design feature had a significant effect on bank behavior. First, banks strongly attempted to avoid triggering the appointment of government directors on their boards and kept high capital ratios meant to enable them to continue making dividend payments without risking undercapitalization. When director appointments did happen, they were associated with improved bank performance and lower CEO pay. Therefore, a potentially fruitful mechanism for the government to bail out banks with capital may be to require in exchange an active role in bank governance along the lines established by the CPP. An alternative solution for infusing equity capital in banks during crises is a capital provision fund, similar in spirit to deposit insurance, as proposed by Song and Thakor (2023). This involves that banks pay premiums ex-ante, before they know whether they will be beneficiaries in a crisis, which are used to build a fund that the government could tap to provide capital assistance for both future bailouts as well as asset purchases. This solution would also address ex-ante adverse selection problems created by the anticipation of future bailouts. Song and Thakor (2023) show that the anticipation of bailouts worsens ex-ante adverse selection, which not only makes the future bailout more likely and more expensive, but also potentially freezes the market even before that. Interesting avenues for future research include such normative and positive analyses of new types of government securities designed to assist banks during crises, as well as capital provision funds.

There has been considerable disagreement regarding the optimal design of CoCos and implementations differ from most theoretically optimal designs proposed. Since all outstanding CoCos are designed to convert on accounting ratios, conversion to equity is subject to regulatory discretion and has thus been deemed unlikely. Concerns have been raised, and there is some evidence too, that CoCos do not constitute going-concern contingent capital, with the implication that they offer no risk absorption before default, nor any preventive effect. The empirical evidence on their effectiveness is limited and is largely due to the (fortunate) lack of financial crises that would require bank recapitalizations, but the recent financial market turmoil provides some concerning evidence. In March 2023, in response to the loss of trust and the run on Credit Suisse, the contingent convertible bonds that were part of the Credit Suisse Additional Tier 1 regulatory capital have been written off (Bolton et al., 2023). The conversion violated the priority order of claims between debt and equity, with Credit Suisse shareholders retaining around $3 billion of equity value, while principal write-down imposed on CoCo bond holders amounted to a wipeout of $17 billion. Concerns that CoCo bonds are in fact nonconvertible have also been raised in early 2016, during the market panic surrounding Deutsche Bank's CoCo bonds. Glasserman and Perotti (2018) discuss this episode and conclude that it leaves the CoCo experiment at risk. The more recent Credit Suisse wipeout poses a real threat to the $250 billion CoCo market.

The recent turmoil in banking does not only provide a laboratory for testing the efficiency of contingent convertible securities, but it raises

many other interesting questions, making banking a topical research area. This is even more so against the background of the rise of fintech and open banking, which bring up a lot of questions about the future of the banking system. Thakor (2020) provides an excellent overview of the literature on fintech and its interaction with banking, which covers both theoretical and empirical literature, and concludes with questions for future research. In doing so he discusses how theories of financial intermediation might need to be changed, how smart contracts might change financial markets, how credit, deposits and lending will change, and how the introduction of cryptocurrencies will affect fiat money, private money creation by banks, and central banking. We will discuss fintech at length in Section 6.

5. Complex security designs

The way financial intermediaries choose to design products has implications for investor decision-making. This issue is especially salient in retail markets populated by unsophisticated investors, as supported by an increasing body of empirical evidence showing that the law of one price is often 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 process information fully and rationally. 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 the 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.

5.1. Supply of complex security designs

What drives the supply of complex securities? Do security designers benefit from increasing the complexity of their product offerings? How does the supply of complex securities depend on consumer sophistication? These are some of the questions we review in this sub-section.

Carlin (2009) studies strategic price complexity in retail financial markets. In a non-cooperative oligopoly pricing model in which firms can 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 the pricing or design of 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 (2011) study the interaction between obfuscation and investor sophistication 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. Obfuscation by financial intermediaries extends beyond the scope of security design and retail markets and has also been shown to play a role in the context of bank portfolio holdings. Babus and Farboodi (2020) 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.

Let us now turn to empirical evidence on the supply of complex securities. Who benefits from the introduction of complexity in security designs? Is there evidence to support the idea that security designers strategically use complexity to exploit consumers? Henderson and Pearson (2011) present evidence suggesting 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. Vokata (2021) provides evidence that yield enhancement products (YEP), which package high-coupon bonds with short positions in put options, offer attractive yields but negative returns, and are not designed to benefit investors. Based on a sample of 28,000 YEP issued between 2006 and 2015, she finds that the embedded fees of YEPs are large enough for their ex-ante and ex-post returns to be negative and the products are often state-wise dominated by simple combinations of listed options. YEPs charge 6–7 % in embedded fees and subsequently lose 6–7 % relative to risk-adjusted benchmarks.

5.1.1. Complexity and product quality

Thus, complexity can be used to obfuscate risk and complex securities do not seem to be designed to benefit consumers. This raises the question of what is the relationship between product complexity and quality? Ghent et al. (2019) 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 use six variables to proxy for product complexity, which are designed to measure the informational demands that MBS deals impose on investors and the intricacies of deal structures. 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. This evidence suggests a negative relationship between complexity and quality, but is it true in general that more complex products have lower quality? The relationship between complexity and product quality is theoretically explored by Asriyan et al. (2023), who propose a model of product design with imperfect information. 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.

A related question is: what is the relationship between product

complexity and the level of trust that consumers can have that the sellers are acting in their best interest? Are the sellers of more complex products to be trusted more or less? What is the relationship between transparency, trust and product complexity? Thakor and Merton (2023) study the equilibrium interaction between trust, transparency (disclosure), and verification (auditing) in a model of endogenous product complexity and transparency. The model suggests that transparency does not build trust per se but rather it substitutes for trust for intermediate levels of product complexity. For high level of product complexity though, only trust enables trade, with the implication that high product complexity can be pursued only by the most trusted producers. Trust in a firm is the probability that investors attach to the firm investing in the good project that they like. At the lowest level of trust, firms choose the least complexity but remain opaque and use instead ex ante third-party verification. For intermediate levels of trust, firms choose greater complexity coupled with increased transparency, but transparency declines as complexity increases. For high levels of trust, firms choose maximum complexity but return to being opaque, disclosing nothing. Thus, complexity endogenously increases with trust, because trust eliminates the need to unravel complexity.

5.2. Demand for complex security designs

While it might not be particularly surprising that FIs have an incentive to increase product complexity if they stand to profit from doing so, it is less clear what are the characteristics of the investor population that make product complexity an equilibrium outcome. 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, their loss aversion or pessimistic beliefs, or their risk preferences.

Coval et al. (2009) study how security design can be used to cater to investors' demand for safe assets in their review on the economics of structured finance and its ability 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 risk 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 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 riskier 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.

Grundy and Verwijmeren (2018) highlight the importance of the preferences of the suppliers of capital, i.e. security buyers, 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.

Vokata (2023) presents evidence from the market for retail structured products that investors display salient thinking, in that they overweight salient product attributes, and this likely plays a role in the proliferation of innovative yield enhancement products. Specifically, security issuers add non-standard, fine-print conditions to artificially increase advertised rates of headline return and downside protection, a practice labelled enhancement. Such enhancement increases headline returns by 11 percentage points, on average, but is largely irrelevant for both expected and realized returns. Nevertheless, household demand is highly elastic to enhancement and is costly to investors, suggesting that demand distortions due to enhancement of salient attributes can have significant welfare implications.

However, security design is not merely used to exploit biases but can also be used to overcome them and can increase welfare. Calvet et al. (2020) provide evidence that 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.

Célérier et al. (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. Thus, security design not only influences market outcomes, but it influences market structure itself, in line with our discussion in Section 3 regarding the two-way relationship between security and market design.

Given that investors fail to price the risks obfuscated through increased product complexity, regulating these markets is important. What can be done to prevent the use of security design to obfuscate complexity and risk? 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.

In sum, this review underscores how the design of financial products significantly influences investor decision-making, especially in retail markets populated by less sophisticated investors. Security designers can employ complexity, either through obfuscation or the sheer quantity of information, to gain market power and increase profitability. For instance, sellers may intentionally complicate pricing structures and strategically obfuscate investor information, thereby preventing the latter from fully understanding the market. Empirical evidence suggests that the increased complexity of securities does not necessarily benefit consumers, as innovative securities issued by banks often exploit uninformed investors. Moreover, complex securities are often riskier, as evidenced by their lower performance and higher default rates. Yet, these risks are not always reflected in their yields, suggesting that investors fail to perceive and price the associated risks accurately. The demand for complex security designs is influenced by various factors,

including the appetite for safe assets and high yields, loss aversion, pessimistic beliefs, and risk preferences more generally.

While financial institutions can exploit these preferences to their advantage, complex security designs also have the potential to enhance economic well-being. Research into how security design can be used to benefit retail investors and how collaboration with regulators can be leveraged to that end is an area of research with important welfare implications. Understanding how consumers process information, their limitations and biases, is an important first step in designing regulation aimed at protecting them, such as information disclosure regulation. It would inform, for instance, on developing effective ways to communicate the risks associated with complex securities, or mandate disclosure of risks in a way that is best understood by investors. This is perhaps even more important against the background of the rise of fintech, decentralized finance (DeFi), and the information economy more generally, which raises important questions such as: Will digital technology and fintech innovations influence the proliferation of complex security designs? Will they ultimately improve or be detrimental to consumer welfare? Could we develop fintech based solutions to overcome the limitations of retail investors? Can AI-based technologies be used to protect and aid consumers in understanding complex security designs and pricing strategies?

6. 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 agrees with the conclusions. Once there is consensus, the distributed ledger is updated, and all nodes maintain their own identical copy of the ledger.

Allen et al. (2020) 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 securities digitization or tokenization, corporate financing, corporate governance, blockchain governance and consensus mechanism design, trading and financial market design. Another relevant review is provided by Thakor (2020), who reviews the literature at the intersection of fintech and banking.

The most widely known type of distributed ledger is the 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. Important classes of cryptocurrency tokens are stablecoins and central bank digital currencies (CBDCs). Stablecoins are designed to maintain a stable peg to another asset, like the U.S. dollar, national currencies, or commodities, and their issuers are supposed to back up the value of coins through holding sufficient reserves to support the value of the stablecoins. CBDCs are a digital or virtual form representation of a country's fiat currency, and unlike cryptocurrencies which are decentralized and unregulated, CBDCs are issued and regulated by a country's central bank.

6.1. Corporate financing interactions

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).[16] 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 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. Why raise capital through an ICO? What are the advantages and disadvantages of this mode of financing and what kind of firms or business ventures are best funded this way? Li and Mann (2018) rationalize the use of digital tokens for launching peer-to-peer platforms. 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. Thus, 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. The following question arises: How does token tradability and the interaction between users and speculators affect platform fragility? Sockin and Xiong (2020) examine this question and 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. Lee et al. (2018) provide empirical evidence that speaks to the role of the "wisdom of crowds," the collective opinion of a group of individuals rather than that of a single expert, in mitigating

[16] 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.

information asymmetries associated with ICOs and in predicting successful fundraising. Using data on a sample of 3392 completed ICOs for the period running from January 2016 through December 2018, they find that favorable ratings by a group of analysts with diverse backgrounds positively predict fundraising success and long-run token performance.

How does traditional equity financing via Initial Public Offerings (IPOs) compare with token-based financing via Initial Coin Offerings (ICOs)? How does the optimal mode of financing depend on the characteristics of the venture to be funded and other frictions? Gryglewicz et al. (2021) 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 (2021) 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.

Empirical research on ICOs has tended to focus on identifying the issuer and ICO characteristics that predict successful financing. Albeit not directly addressing security design issues, the literature has shed some light on the token features that predict successful ICO financing. Howell et al. (2020) provide evidence that liquidity and trading volume are higher for tokens that offer voluntary disclosure and provide a signal of quality and the potential value of the project. Additionally, the professional background of an entrepreneur is also strongly associated with ICO success. Amsden and Schweizer (2018) document that the tradability of tokens or coins as well as the uncertainty and quality of venture also matter. Specifically, ICO success is negatively correlated with venture uncertainty (no source code available, not being on Github and Telegram, low percentage of tokens retained) and positively correlated with venture quality (better connected CEOs, larger team size). Adhami et al. (2018) show that ICO success is more likely if the code source is available, when a token presale is organized, and when tokens allow contributors to access a specific service or to share profits. Fisch and Momtaz (2020) show that institutional investors have positive impact on post-ICO performance. They attribute this to investors' superior screening and coaching abilities, which enable them to partly overcome the information asymmetry surrounding the ICO process. Lyandres et al. (2022) review and confirm finding of the literature on the determinants of ICO funding success as well as post-ICO operating performance. They provide additional findings on the role of the entrepreneurs' skin in the game, measured as the inverse of the percentage of tokens available for sale, in terms of increasing post-ICO code revision activity and post-ICO platform adoption.

6.1.1. Moral hazard and smart contracts

Going beyond financing, how does token financing compare with traditional equity from the perspective of incentivizing effort and aligning the incentives of insiders and outsiders? Garratt and Van Oordt (2021) 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, therefore, eliminate in an automated and conflict-free way some contracting frictions like the need for costly verification, enforcement, or the risk of renegotiation. Thus, can smart contracts optimally incentivize effort, and perfectly address moral hazard and dynamic inconsistency issues?

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.

By enabling commitment to predetermined rules, smart contracts and the blockchain technology can address dynamic inconsistency problems and as demonstrated by Cong et al. (2022), 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. 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. Insofar as it enables commitment to predetermined token-supply rules, blockchain technology can address this conflict and the underinvestment problem.

Notwithstanding the benefits brought about and the frictions overcome by the blockchain innovation, token-based financing can be rendered inferior relative to traditional equity if it is affected by problems such as limited commitment in new token issuance. Catalini and Gans (2018) 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. When there is lack of commitment in token issuance, 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 if the latter only offers rights to a certain amount of output or a fraction of the future revenue. Such simple token designs are economically inferior to equity and lead to over- or under-production relative to the production quantity that maximizes the venture's aggregate profits. However, an optimally designed token contract yields the same payoff as equity and debt. 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. In the presence of entrepreneurial moral hazard, tokens can finance a strictly larger set of ventures than equity.

An empirical overview of smart contract applications and design patterns is provided by Bartoletti and Pompianu (2017) who quantify the usage of smart, focusing on the two most widespread platforms supporting their use, namely Bitcoin and Ethereum. The authors propose a taxonomy of smart contracts which involves sorting them into categories which reflect their application domain, namely financial, notary, wallet, game, library. They further identify nine common design patterns, which include token, authorization, oracle, randomness, toll, and quantify their usage in contracts and in relation to the associated category.

6.2. Corporate governance interactions

What are the implications of the blockchain innovation for corporate governance? Several 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 need 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 (DAOs). These are entities 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.

In principle, DAOs overcome the need for centralized leadership which underpins traditional organizations and which entails that managers or directors have formal decision rights. Instead, the members of DAOs collectively make decisions by voting on proposals and the governance process is encoded and executed via a smart contract. But how are DAOs governed in practice? Appel and Grennan (2023) examine the control of DAOs by analyzing 10,639 proposals across 151 DAOs and find that rather than democratizing decision-making, a small number of entities exert control over most decisions. So, although the autonomous nature of DAOs means that there is no need for monitoring agents to control the organization, large participants can capture control and impose their preferences on the system. This is an issue in the presence of conflicts of interest and raises the question of how such conflicts affect the platform. Han et al. (2023) investigate potential conflicts of interest between a large participant and many small participants in the context of a theoretical model of DAO governance which features strategic token trading under token-based voting. They show that ownership concentration impacts negatively platform growth, but platform size, token illiquidity, and long-term incentives can mitigate the negative effects. Using novel voting data on over 200 DAOs between 2020 and 2022, they confirm these predictions. Specifically, the authors document a negative relationship between platform growth and the voting power concentration measured using the Herfindahl-Hirschman Index and the top three voters' ownership, which is dampened the higher the platform size and illiquidity, as illustrated by interaction terms. They also document a higher growth rate for platforms that shifted from a one-token-one-vote model to a staking model which allows investors to lock their governance tokens to gain more voting power and enhance their investment yields.

An important issue when it comes to platforms that collect and use personal data from users in their production has to do with governing the use of such data. How should the use of personal data and technology be governed on decentralized platforms that collect users' data through their transactions on these platforms? Bena and Zhang (2023) study the optimal design of decentralized governance using blockchain technology for a platform that leverages user data as input in production. They show that token-based decentralized governance has the potential to align the interests of platform founders with those of users and is also the preferred governance regime for founders. Decentralized governance using a governance token leads to a higher user surplus compared to the centralized governance of a traditional firm. The platform's founder can achieve greater output by offering token buy-back, which incentivizes early platform adoption by enabling transfers among users at a later date.

6.2.1. Blockchain governance

Considering the possibility of replacing traditional governance mechanisms with blockchain-based systems and automated decision-making through smart contracts raises questions regarding the governance of the blockchain itself. 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.[17] 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 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. What mechanisms can be employed to achieve consensus and govern decentralized record-keeping systems? 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.[18]

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

[18] 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 (2018) provide technical foundation for any economic analysis of PoW protocol, and center their analysis on resource usage, competition and market structure regulation.

In the PoS blockchain, on the other hand, voting power is based on the stake that each node or participant 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. Alternatively stated, the governance of the blockchain need not be a function of security holdings, but in the PoS blockchain there exists a relationship between security holdings and control rights. Saleh (2021) 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.

More generally, how should consensus mechanisms be designed to ensure record-keeping integrity? Abadi and Brunnermeier (2018) 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 breakdown 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 the ledger) in order to achieve consensus. Irresberger et al. (2021) provide an empirical overview of the public blockchain ecosystem and propose three key economic attributes as the determinants of blockchain user utility: adoption, scale, and security. According to their analysis, PoW blockchains dominate in adoption, delegated POS blockchains dominate in scale, and blockchains using nonstandard protocols dominate in security.

It is important to note that although the PoW blockchain is designed to achieve decentralized governance, empirical evidence challenges this idea. For instance, Makarov and Schoar (2021) show that the Bitcoin eco-system is still dominated by large and concentrated players. Bitcoin mining capacity is highly concentrated, with the top 10 % of miners controlling 90 % and just 0.1 % controlling almost 50 % of mining capacity and most of the mining capacity, between 60 % to 80 % is located in China. This raises the question of how decentralized distributed ledger technology applications and implementations really are. At this point it is not clear what are the distributed ledger technology use cases that are most likely to be welfare enhancing. Makarov and Schoar (2022) provide an overview of cryptocurrencies and decentralized finance, highlighting the potential benefits and challenges brought about by this technological development, also discussing the ways to regulate the DeFi system that would preserve a majority of benefits. We have discussed a range of applications and interactions within the field of finance, but other examples include supply chain management, property rights and land registration, healthcare and medical records, digital identity records, and voting applications.

6.3. Trading and financial markets interactions

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 raises the question of whether 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.[19] Lee et al. (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 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 intermediated markets.

Rather than assuming a market based on token systems that resolves settlement risk, Lee et al. (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 (2019), 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 the creation of a decentralized digital ledger of transactions which are shared 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

[19] 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.

enable small denomination investments into safe government bonds which fund the development of green projects. They also 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 CO2 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 BIS (2021a) and public permissionless blockchain infrastructure BIS (2021b), and streamline processes which include origination, subscription, settlement and secondary market trading.

However, there have also been more questionable applications of DLT to the field of climate finance, both of which represent rapidly evolving fields whose regulation 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 (FT, 2022). 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 tokenize. 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.

To conclude, the development of the distributed ledger technology has had important implications in terms of the way organizations can be financed and governed. It has also had implications for financial markets and trading, which are best understood in light of the fact that financial securities can be digitally represented. The digitization of assets enables the use of smart contracts as the basis for transference, which raises questions about the future of financial intermediation. Its wide range of applications has the potential to fundamentally change the workings of the economy and financial system as we know it. It raises both opportunities and risks, and we have yet to understand them. The threats to financial stability posed by private cryptocurrencies, which are decentralized and unregulated, have led to intensive debates among policymakers and monetary economists about whether central banks should issue CBDCs or play a supporting role in issuing CBDCs. Research in this area has grown considerably in recent years, many countries are exploring CBDCs and some have already launched CBDC.[20] However, the full implications and changes in the financial and economic landscape remain to be assessed.

Recent events in stablecoin markets have challenged the idea that they are indeed stable. The algorithmic stablecoin terraUSD (UST), was supposed to maintain a 1:1 peg with the US dollar, but collapsed in May 2022, wiping out $50 billion in valuation. The value of its companion token, LUNA, which was meant to stabilize UST's price also fell. As detailed by Liu et al. (2023), at the center of the collapse was a run on a blockchain-based borrowing and lending protocol (Anchor) that promised high yields to its stablecoin (UST) depositors. USDC (USD Coin) is another key example. Although designed to be a stablecoin, pegged 1:1 with the US dollar and fully backed by reserves, concerns have been raised about the transparency and composition of the reserves backing the coin. In March 2023 Stablecoin USDC broke the dollar peg after revealing it had exposure to the bankrupt Silicon Valley Bank. Thus, an interesting and important issue is whether stablecoins can be designed in such a way that they are stable. D'Avernas et al. (2022) study the stability of various pegging mechanisms and the optimal design of stablecoin platforms, focusing in particular on the contribution of collateral and decentralization to the stability of stablecoins. They show that the platform's limited commitment to policies that prevent it from extracting seigniorage by overissuing stablecoins, ultimately undermines the peg. However, commitment can be substituted by combining decentralization with collateral. The issue of whether stablecoins can be designed so that they are truly stable is an important area for future research and there are still many setups and issues to be explored. The potential instability of stablecoins can have important spillovers to the real economy since they are backed by real-world assets, and for instance a run on stablecoins could spill into bond markets as issuers may have to sell U.S. Treasuries to honor redemptions. Understanding the spillovers and interactions between cryptocurrency markets and the real economy is highly important.

[20] See the Central Bank Digital Currency Tracker https://www.atlanticcouncil.org/cbdctracker/ .

7. 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 sustainable or impact investing. The idea behind sustainable 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.

7.1. Public and hybrid solutions for financing sustainability

Social Impact Bonds (SIBs) have initially been 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 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 of 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. A number of questions arise. How are SIBs structured from a funding perspective? How do they compare to alternative funding arrangements typically used by public administrators? Can financing through standard financing arrangements involving traditional debt and/or grants

produce the same outcomes as financing through SIBs? Can SIBs finance projects that traditional debt finance cannot? Below, we review a number of papers that address these questions.

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 so-called impact investors that 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 protects the first two categories and is essentially a substitute to government funding.

Wong et al. (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.

Pauly and Swanson (2017) 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. Thus, investors can play an important role in the context of an SIB and the value of SIBs in terms of funding innovation will be strongly context-dependent and need not produce any difference in outcome relative to standard financing arrangements.

Tortorice et al. (2020) 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.

A question that is broader and goes beyond the specific SIB design is what is the role of impact investing relative to grants? Can more impact be achieved through investments or donations? 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. Investments can achieve more impact than a grant for organizations that would be 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 its financiers rather than a net receiver. Grants achieve the first-best outcome for organizations that are not sustainable under the grant financing regime. Defined as such, it is organizational sustainability that leads to impact investing, rather than the other way around.

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 unemployment, recidivism or improving social care in a clearly defined geographical area such as a city or region.

7.2. *Market solutions for financing sustainability*

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.[21] 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 deriving utility from funding the provision of non-pecuniary outcomes rather than having to be incentivized.

The change in investor preferences is evidenced by a sharp increase in the market for sustainable finance. The global capital deployed to addressing environmental, social and sustainability challenges has increased from an annual volume of $12 billion in 2007, to $1527 billion in 2022, reaching a total cumulative volume of approximately $5910 billion as of 2022. The market has also seen a proliferation of financial products.[22] Green loans and bonds, social bonds and sustainability

[21] Corporate Social Responsibility (CSR) is another 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.

[22] It is worth noting that markets for sustainable or green debt, are in effect catering to a clientele with specific tastes and are not conceptually different from, say, the market for Islamic bonds, or Sukuk, which are designed to be Shariah compliant (for details see Ariff, Safari and Shamsher, 2012; Alam, Hassan, and Haque 2013; Chen, Cherian, Li, Shao and Subrahmanyam).

bonds pledge the proceeds to financing projects that deliver environmental, social or sustainability benefits, respectively.[23] 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 specific 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 change in investor preferences is based on the belief that the failure to prioritize sustainability will have negative economic consequences and can lead to catastrophic tipping points that would not support life on Earth. While the hybrid funding solution implemented with SIBs is specifically designed to offer investors better returns for funding projects that deliver positive sustainability outcomes, the idea behind the design of the purely private funding solution is that investors are willing to forgo returns in exchange for positive sustainability outcomes. In theory, when investors care about both monetary and non-monetary outcomes, they should be willing to trade-off financial returns by paying a risk premium, typically called a green premium, for the non-monetary benefit (Pástor et al., 2021). However, the evidence on the existence of a green premium is mixed.[24]

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. How can this conflict be managed or resolved? Hart and Zingales (2017) prescribe corporate governance and shareholder activism as a means to balance profitability against social harm. But what role can financial contracting and security design play? 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 et al. (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 over-emphasize 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 align incentives among these heterogeneously motivated investor groups if contracts are made contingent on realized social output. Specifically, incentive alignment 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 generating negative externalities 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.

What if firms are not merely a pass-through implementing the mandates of heterogeneous groups of investors and agency frictions play an important role? Barbalau and Zeni (2022) focus on the role of contingencies in aligning incentives and enforcing commitment to non-pecuniary outcomes, generically called green outcomes. Investors value 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 ensure commitment to outcomes by making investors' return contingent on the realized sustainability performance of the issuer. The contingent debt contract achieves the first-best 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 there is asymmetric information about firms' abilities to exert effort vs manipulate reported outcomes. Thus, measurement frictions play an important role in preventing the use of security design and contracting solutions to address agency conflicts and achieve impact.

7.2.1. *Evidence on impact*

Empirically, the following questions arise: Do these contracts provide sufficiently strong incentives for borrowers to deliver positive sustainability related outcomes? In other words, do the firms issuing such sustainable securities improve their sustainability performance? Are some of the contract designs observed in the market better than others at providing incentives? A growing literature addresses these questions and aims to understand more generally who benefits from the issuance of such debt contracts and whether they have an impact.

There is some evidence that green bonds, especially externally certified ones, are effective in terms of improving issuing firms' environmental performance. Flammer (2021) documents that green bond issuers improve their environmental performance post-issuance as evidenced by a significant reduction in CO2 emissions and an improved environmental score. Fatica and Panzica (2021) show that green bonds that are used to refinance existing green projects do not materially impact firms' environmental performance but green bonds which are utilized for new projects have more impact. Interestingly, the literature studying green bonds seems to have focused more on the implications of green bonds issuance in terms of issuers' financial performance and market reactions, and not so much on quantifying the sustainable impact that they are presumed to enable (Bhutta et al., 2022).

The empirical literature focusing on sustainability-linked debt provides mixed evidence regarding their impact, but it is worth noting that this is a novel class of securities, most of which have future target dates that have not yet been reached. In other words, it is still early to assess whether these targets have been met and to draw conclusive evidence on their effectiveness. Instead, the literature has focused on studying their pricing and in particular whether the pricing incentives embedded in these securities are sufficiently meaningful to drive improvements in sustainability performance.

Loumioti and Serafeim (2022) document that SLLs have lower

[23] 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.

[24] 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, 2022), studies using tighter methodological approaches do not find any such evidence (Larcker and Watts, 2020; Flammer, 2021). 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.

interest rates compared to otherwise equivalent conventional loans and are granted to borrowers with lower ESG risk. They find no significant association between ESG risk and the pricing adjustments included in the loans, which is suggestive of poor target setting and interpreted as evidence that these contracts are not incentivizing high ESG risk borrowers to make ambitious improvements. On the other hand, Carrizosa and Ghosh (2022) provide evidence that SLLs are designed to provide greater incentives to borrowers to improve ESG performance when borrowers' ESG- and credit-risk is high, but also note that at least some contracts provide weak sustainability performance incentives. Kim et al. (2023) find that SLL loan borrowers enjoy a net pricing advantage compared to green loan borrowers. SLL loans are opaque and vary widely in the extent of their contractual disclosures, with borrowers with low quality disclosures about contract features experiencing a deterioration in ESG scores after loan issuance, whereas the ESG performance does not change for borrowers with high quality disclosures. Dursun de Neef et al. (2023) contrast the ESG performance of firms issuing SLLs versus green loans, and find that whereas issuers of SLLs improve their overall ESG performance in the long term by increasing their environmental and governance scores, green loan issuers prioritize their environmental goals at the expense of their social performance. Du et al. (2022) find SLLs do not have lower initial loan spreads and it is lenders that seem to be the ones capturing most benefits from issuing SLLs by attracting more deposits post-issuance, while not necessarily taking on more risk. On the other hand, potential discounts for ESG performance do not seem to provide sufficient incentives for SLL borrowers to engage in meaningful changes in their ESG profile.

Kölbel and Lambillon (2022) estimate that SLB issuers benefit from a sustainability premium which exceeds the average penalty. Specifically, the average financial savings for issuers are more than 60 % greater than potential coupon step-up penalties. In other words, for some SLB issuers the financial savings are higher than the penalty, and SLBs are issued purely for financial optimization without a real commitment to carry out sustainability improvements. Ul Haq and Doumbia (2022) point to structural loopholes in the design of SLBs, which tend to have late target dates and embed call options. They document that SLB which embed step-up penalties are associated with significantly later target dates, target dates are even closer to maturity the higher the step-up penalty and penalties imposed on early call are more lenient.

In sum, while the design holds promise, the current pricing of these instruments and the regulation surrounding their issuance may not be at a stage where they drive meaningful sustainability impact. It will be interesting to see the realized performance of these instruments and how the issuers fare in terms of reaching their targets. Another important issue, related to additionality, is related to designing targets that carve out outcomes that were going to be achieved anyway, and more generally designing targets that are robust to manipulation. Further interesting research questions, related to broader issues on ESG and CSR in corporate finance are discussed by Gillan et al. (2021).

7.2.2. Designing compensation

Recent years have also seen a rise in ESG-based compensation, raising questions about the forces giving rise to such observed outcomes as well as the efficiency of such contracting. Chaigneau and Sahuguet (2023) study how to design ESG-based compensation in a setup in which a socially responsible board, which represents the firm's shareholders, can align the manager's interests using incentives based on earnings, stock price or ESG scores. The model accounts for the fact that the firm's manager understands how ESG scores are constructed, and can potentially game the methodologies. When the board is more socially responsible than investors, who set the stock price, incentives should be based on the stock price and ESG scores. Otherwise, if investors are more socially responsible than the board, then the optimal compensation contract is earnings-based, but if these two parties have the same social preferences, the manager's compensation should only be made contingent on the stock price. Bebchuk and Tallarita (2022) provide an empirical analysis of the increasing trend of using ESG performance metrics for CEO compensation and discuss its fundamental flaws and limitations. They note that insofar as ESG metrics commonly link CEO pay to a limited number of welfare dimensions benefiting a limited subset of stakeholders, they could ultimately hurt aggregate stakeholder welfare. Another issue is that currently these contracts are not subject to sufficient scrutiny from outside observers to ensure that they are designed to provide effective incentives rather than serve the interests of executives and exacerbate agency problems. Evidence on their effectiveness is limited, partly since this a fairly recent phenomenon, but also due to the limited availability of information. Walker (2022) examines ESG-linked CEO pay arrangements at a subset of companies with leadership positions on the Business Roundtable. He provides evidence that explicit, non-discretionary ESG incentives are economically insignificant relative to incentives to maximize the stock price which arises from shares owned and unvested or unexercised equity-based compensation.

Moving beyond ESG-linked pay, how can employment contracts more generally be designed to incentivize the implementation of projects with non-pecuniary outcomes? Adachi-Sato (2021) studies how principals can use the length and timing of wage contracts to motivate profit-maximizing managers to pursue long dated socially oriented projects. The paper builds on the multi-task principal-agent model of Holmström 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. The compensation contracts considered are a short-term wage contract that determines the second period wage at the beginning of the second period or a long-term wage contract that determines the second period wage at the beginning of the first period. Empirical evidence on how impact is incentivized contractually is provided by Geczy et al. (2021). They analyze the compensation contracts of impact funds and 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.

7.2.3. Implementation issues and regulation

Despite increased investor interest, the sustainable finance market is limited in its growth by the limited availability of reliable information and measurement systems, as well as guidelines surrounding the design of robust targets. 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 as 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 et al., 2022). 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. Allen et al. (2023) show that a carbon-contingent security design, which involves increasing issuers' cost of debt if they fail to achieve an emissions reduction target and vice versa, can under certain conditions be

equivalent to a carbon tax. When there is no political support for regulation and the capital deployed through carbon-contingent financing is sufficiently high, the market solution to pricing carbon can fully substitute regulation and improves welfare. However, the existence of financial markets for pricing carbon weakens support for regulation and can shift the economy from one that supports a tax to one that does not, resulting in welfare and emission reduction losses. This raises the question: how much should we rely on financial markets to reduce negative externalities and enable the transition to a low-carbon economy? The implementation of carbon pricing regulation does face serious barriers such as lack of political support and the stringency of other problems, such as poverty. Furthermore, even when support exists, implementing regulation can be challenging due to financial constraints and leverage (Heider and Inderst, 2021; Döttling and Rola-Janicka, 2022; Ivanov et al., 2022). However, substituting the difficult-to-implement regulatory solution to reducing externalities with the financial market solution is likely insufficient and potentially problematic. There is evidence that markets for sustainable investing fail to internalize aggregate welfare implications and can misallocate resources (Green and Roth, 2021; Oehmke and Opp, 2020; Hartzmark and Shue, 2023), distort market power and product market competition (Bisceglia et al., 2022), and can delay reform (Gupta et al., 2022; Huang and Kopytov, 2023).

In terms of areas for future research, it is important to understand not only the role that security design and financial innovation can play in reducing negative externalities, but also the interaction with regulatory tools such as investment mandates, carbon markets and taxation.[25] The role of financial innovations in which governments play a role, such as blended finance that leverages public funds to catalyze investments from capital markets, is also important, especially when it comes to channeling funds towards financing the transition of developing economies.

It has been shown both theoretically and empirically that socially responsible investments can have counterproductive implications. Green and Roth (2021) show that ESG investing strategies that focus on the social value of the companies included in their portfolio, with no regard for the implications of these investments on total welfare, allocate their capital inefficiently from the perspective of generating impact and financial returns. Gupta et al. (2022) highlight that socially responsible investors who value acquiring firms with high negative production externalities that they can reform, create trading gains that can actually cause a potential delay in reform. Empirical evidence on the counterproductive effects of sustainable investing is provided by Hartzman and Shue (2023), who assess the implications of common strategies which direct capital away from brown firms and towards green firms. Such strategies are estimated to be counterproductive since increasing the cost of financing for brown firms leads to large negative changes in firms' environmental impact, while a reduction in financing costs for firms that are already green leads to small improvements in impact at best. In other words, such strategies make brown firms browner without making green firms greener. Relatedly, Heath et al. (2022) document that socially responsible investment funds buy firms with green characteristics, but these characteristics do not meaningfully improve after they are purchased.

The implications of responsible investing seem to depend importantly on the investors' preferences and the drivers behind their investment strategies. For instance, investors may altogether refuse to invest in polluting companies, may only care to minimize the carbon footprint of their portfolio holdings or they can allocate capital such that they drive aggregate reductions in carbon emissions. Another way to think about this is in terms of whether agents act to achieve impact, or their actions are based on what is the "right" thing to do irrespective of impact. There is no consensus yet in the literature on how we should conceptualize and model green preferences, but a paper that provides a first general framework is Dangl et al. (2023).

Having pointed out open research questions throughout this section, we conclude by noting that there has been an important change in investor preferences and, consequently, the mode of funding projects that yield public benefits. Such projects used to be funded with public money through grants or mediated by public entities through hybrid funding solutions such as pay-for-success bonds. In recent years, we have seen considerable developments from the private sector with financial markets deploying increasingly more capital to projects with sustainability-related outcomes, through securities such as green or sustainability-linked bonds. Importantly, this change has entailed a fundamental shift in the design of securities used to fund projects that yield non-pecuniary outcomes. In the context of the hybrid solution, the financial return to investors depends positively on the performance of the project funded, which is meant to incentivize and reward investors for funding projects with non-pecuniary outcomes. On the other hand, in the context of the private solution, the return to investors depends negatively on the sustainability performance of the funded projects, and it is investors that incentivize and reward borrowers for generating non-pecuniary outcomes. Evidence suggests that there is still room for improving the pricing of security design innovations which make payoffs contingent on the sustainability performance of the issuer. Devising solutions, such as robust measurement systems and consistent reporting standards, is key to the development of these markets and to ensuring that private capital will still flow towards funding the provision of public benefits. However, markets should not be entirely relied upon, and governments will still need to act - if not to regulate negative externalities, to ensure that sustainable finance markets function properly.

8. Healthcare finance

The development and delivery of healthcare are crucial for individual well-being and the functioning of the economy, as highlighted by the recent COVID-19 pandemic. To advance healthcare, funding for biomedical research and development (R&D) is essential. Biomedical R&D is a complex and costly process, requiring significant investments for research, clinical trials, and the development of medical technologies, and which relies extensively on external funding sources, such as government grants and private investments, for financial support. Notwithstanding the importance of healthcare to the global economy, an emerging literature has documented significant underinvestment in biomedical R&D relative to the social optimum, which is due to a persistent R&D "funding gap". In this section, we discuss why this funding gap arises, what is the role that financial intermediaries (FIs) can play in closing it, the role of financial innovation and securitization-based solutions, as well as options-based security design implementations.

What gives rise to the funding gap in biomedical R&D? Lo and Thakor (2021) provide an overview of the institutional characteristics, as well as the costs and risks that biopharmaceutical companies face during the process of drug development. The substantial capital requirements involved in developing and bringing new drugs to market make these firms highly reliant on external financing and expose them to financing frictions and capital market imperfections. The institutional features surrounding the drug development process, such as lengthy development timelines, technical difficulties, regulatory complexities, and uncertain payoffs, further amplify these external financing frictions, leading to underinvestment in R&D and in therapies that are potentially valuable from a societal perspective.

What is the role that financial innovation, and FIs more generally, can play in attenuating the funding gap and financing frictions faced by biomedical R&D firms? Lo and Thakor (2023) provide a comprehensive review of the literature on the funding of biomedical innovation, discussing the role that FIs can play as well as the role of security design and

[25] Relevant existing research, the review of which falls beyond the scope of this review, includes Heider and Inderst (2021), Oehmke and Opp (2022), Inderst and Opp (2022), Biais and Landier (2022).

regulatory assistance. FIs can play an important role in facilitating the flow of funds from investors to firms by reducing financing frictions related to adverse selection, moral hazard, the non-pledgeability of knowledge assets, and other contracting issues. They can do so by driving financial innovation, using tools such as financial engineering and securitization which can help share risks with market participants that are more able or willing to bear them. This can increase aggregate investment in drug development and can play an important role in closing the funding gap in biomedical R&D.

Financing investment in drug development projects using traditional financing sources such as private and public equity is difficult because such projects have large capital requirements, low probabilities of success, and long time-horizons. A growing literature explores the role of financial engineering techniques such as securitization in increasing the flow of funds to biomedical R&D, particularly in areas where there may be greater societal need but higher risks for firms. Fernandez et al. (2012) first proposed the idea of a "megafund" which pools together a number of different biomedical projects into a single financial vehicle. The idea is that, in line with basic portfolio theory and the notion of diversification, some of the individual risks associated with these projects will cancel each other out, reducing the overall risk of the fund. This would then enable the fund to engage in securitization and issue tranches of debt as well as equity to finance the development of the underlying portfolio of pipeline drugs and their associated intellectual property. By providing a more attractive risk-return profile to large investors, the flow of funds to such investments can increase. Simulation results indicate that this financial structure can yield reasonable returns for both equity and debt investors and point to the potential of commercializing biomedical research through securitization tools.

There have been several extensions of the megafund concept. Fagnan et al. (2013) extend the multistate, multiperiod simulation framework with path-dependence and correlated asset valuations proposed in Fernandez et al. (2012) to include an analysis of the impact of government guarantees on the returns to bond and equity holders. They estimate that even a small third-party guarantee, in expected value terms, can materially improve the economics of these so-called research backed obligations. A related solution, which can be placed at the intersection of financial innovation and government assistance is discussed in Lo and Thakor (2023). To facilitate the flow of credit into the biopharma sector, government assistance can complement innovations in a manner similar to that used for home mortgage lending in the 1930s or farm credit. Specifically, the government could serve as an intermediary in mechanism design between investors and biopharma firms or create an agency that acquires biopharma loans, then securitizes them, allowing investors to buy securitized claims against a large and diversified pool of biopharma loans.

How can the megafund funding solution be adapted to suit various features and characteristics of the drug development projects in the portfolio? Montazerhodjat et al. (2016) extend the megafund concept to analyze the use of dynamic leverage as a function of the clinical phases of portfolio assets. The idea is to initially finance the portfolio of drug development assets using equity, and gradually introduce debt as the assets mature and start generating cash flows. Numerical simulations indicate that dynamic leverage can boost equity returns relative to static capital structure and adds significant value relative to equity-only financing without jeopardizing debt performance or increasing risk to equity investors. The degree of correlation of success or failure between portfolio development projects is critical to the success or failure of the megafund, with statistically independent projects favoring its success. Lo and Siah (2020) extend the megafund framework to account for correlation between phase transitions in drug development projects. Although the performance of the megafund becomes less attractive when correlation between projects is introduced, the risk of default and the expected returns of the vanilla megafund remain promising even under moderate levels of correlation. In addition, a leveraged megafund outperforms an equity-only structure over a wide range of assumptions about correlation and success probabilities. Further dimensions along which the megafund idea has been extended, as well as applications to disease-specific portfolios of drug targets, such as rare diseases, ovarian or pediatric cancer, are reviewed in Lo and Thakor (2021, 2023). The megafund approach is more amenable to some types of diseases than others. The design of the funding structure, i.e., public-private partnerships, government guarantees and philanthropic support, depends on target diseases and correlates with factors such as capital requirements, legislative incentives, correlation of failures among disease targets, tail and downside risk. For instance, a portfolio approach within a public–private partnership including government guarantees is more suitable for ovarian cancer therapeutics, reducing tail risk while increasing expected returns to investors (Chaudhuria et al., 2019), while a portfolio approach with government guarantees and philanthropic support for pediatric oncology therapeutics has the potential to eliminate significant downside risk while maximizing expected returns (Das et al., 2018).

Another financial innovation that could play a role in reducing the funding gap in biomedical R&D is the "FDA Hedges" idea proposed by Jørring et al. (2017). FDA hedges are essentially insurance contracts that pay off upon the failure of individual drug projects to gain FDA approval, and are similar to credit default swaps. Such contracts would provide direct risk-sharing benefits to medical R&D investors and developers by allowing them to share the risk associated with the FDA approval process with broader capital markets. The authors develop a theoretical model to highlight the informational frictions that allow these contracts to reduce underinvestment in R&D and enhance welfare and discuss mechanisms under which they can be traded. An advantage of these contracts is related to their pricing, as they have little systematic risk and thus would not demand a systematic risk premium. Lo and Thakor (2021) propose an innovation that is similar in spirit by approaching the problem from the perspective of deriving the optimal financing for R&D-intensive firms. They take a mechanism design approach to derive the optimal set of securities to fund biopharma R&D and reduce underinvestment and show that when the feasible set of contracts is augmented to include more general payout schemes and not just equity, underinvestment in R&D is reduced. Specifically, implementation involves a mechanism which combines equity with put options, and allows investors to insure firms against R&D failure and firms to insure investors against high R&D payoffs not being realized.

In addition to the important role played in the drug development process, security design and financial innovation can also play a key role in incentivizing investment in social drivers of health (SDH) interventions such as such food insecurity, transportation, and housing (Karaca-Mandic et al., 2023). SDH interventions yield benefits over long periods in terms of healthier populations and can thus reduce future healthcare costs but require sizeable up-front investment. These benefits are essentially positive externalities which may not be fully internalized by the healthcare organizations making the investments and can even accrue outside the managed care system. Karaca-Mandic et al. (2023) refer to this as a "wrong-pockets problem" and discuss how Medicaid managed care organizations have little incentives to invest in SDH interventions because they do not get to reap the full return as cost savings. They propose a financial innovation called a SDH bond which would be issued jointly by multiple Medicaid managed care organizations under a special purpose vehicle (SPV). The SPV would commit using the proceeds to fund SDH interventions for the overall enrollee populations of the managed care organizations issuing the bond. Similar in spirit to the green, social and sustainability bond instruments discussed in Section 7, this bond would cater to altruistic investors who derive benefits from pursuing investments that promote social drivers of health. Bond repayment by each managed care organization would adjust over time based on each organization's enrollment and would thus address the timing mismatch of SDH investments and their realized benefits in terms of cost savings, coupled with the volatility of Medicaid enrollment.

In sum, the provision and development of healthcare, which are

critical for individual health and economic welfare, hinge on the funding of biomedical R&D. Despite its importance, a significant gap in investment in biomedical R&D has emerged, perpetuated by institutional characteristics, high costs, risks, and external financing frictions that biopharmaceutical firms face during drug development. There is an important role that FIs and financial innovation tools like securitization can play in bridging the funding gap. Solutions such as the megafund approach pool multiple biomedical projects into a single financial vehicle, reducing risk through diversification. Other financial innovations, like "FDA Hedges", function as insurance contracts paying out when a drug project fails to gain FDA approval, reducing underinvestment in R&D. Government assistance, complementing these financial innovations, can aid the flow of credit to the biopharma sector.

The literature on the funding of healthcare and biomedical innovation is relatively limited and mainly focused on securitization-based solutions. Given the importance of funding biomedical research, the potential of financial innovation and security design to increase the flow of funds to this sector and close the funding gap, there is a strong case for more normative research into contracting innovations. A good starting point is the review of the literature on financial intermediation and the funding of biomedical innovation by Lo and Thakor (2023). In addition to providing a good background on institutional details and challenges, the paper also develops a simple model of biomedical R&D financing which captures the key frictions of the drug development process, and which highlights how underinvestment can arise. The model features a firm which seeks financing for staged R&D and can issue either debt or equity. The frictions that it faces compel it to rely on equity rather than debt, which implies underinvestment in R&D relative to the social optimum. They discuss the possible role of security design innovations in facilitating banking and capital market solutions and argue that such innovations can be a powerful force in helping banks and markets to close the R&D funding gap.

Ultimately, the use of financial innovation and security design may help increase funding in biomedical research and close the gap. Given the complex landscape of biomedical R&D funding, several avenues for future research emerge from the discussion. What other financial innovations or tools can be designed or adapted to facilitate funding for biomedical R&D and/or SDH interventions? Presumably we can use financial engineering and subsidies to attract capital through the promise of high financial returns. But can the rise of stakeholder capitalism and its inherent concern for social welfare be leveraged to increase the flow of capital to biomedical R&D? If so, how? If not, what are the frictions, and can security design be used to overcome them? Could technology play a role?

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, and it also enables 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 2007–2008, 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 investors' 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.

Throughout the paper, we have referred to open research questions and promising areas for future research. We conclude by pointing to three big trends around which there is intense public interest, and which will have significant implications for finance. First, the rise of stakeholder capitalism challenges ideas around the purpose of corporations. The big question is how can security design and contracting innovations be employed to change the objective function of the firm from maximizing profits to maximizing social welfare? What is the role that security design can play in ensuring that capital is channeled towards investments that have most impact? How can we make sure the beneficiaries of those funds will use it to deliver most impact? Second, the rise of big data and changes in technologies for collecting and processing information have made data a key production input that we do not yet know how to value or contract on.[26] It is changing business models, the way companies generate value, the types of securities they optimally issue to allocate cash flows and control rights, and raises new governance issues such as those related to privacy. Fintech innovations and open banking have the potential to fundamentally change the banking landscape, the way in which securities are traded, stored and the type of security design innovations introduced by financial intermediaries. Third, artificial intelligence and the potential for decision-making automation has implications that permeate all fields which have a human decision-making component. How should corporations run by machines be financed and governed? Contracting and security design as we know them may no longer have a role in providing incentives for optimal decision-making. Will agency frictions no longer be relevant? How are markets and overall economies going to change as machines play an increasingly important role? What are the differences between decision-making by humans and machines?

[26] Work on this is at a relatively early stage; some key references are Farboodi and Veldkamp (2021, 2023), Veldkamp (2023).

CRediT authorship contribution statement

Franklin Allen: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Adelina Barbalau:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

Data availability

No data was used for the research described in the article.

Appendix

CORPORATE FINANCE

Capital Structure and the Allocation of Cash Flows

Ex-ante asymmetric information and adverse selection

- Firm insiders are typically assumed to be relatively more informed. Central to security design is sensitivity of payoffs to insiders' private information (Myers and Majluf, 1984) and missing contingencies in optimal contracts are a natural response to adverse selection (Holmström and Milgrom, 1991; Allen and Gale, 1992).
- Numerous asymmetric information refinements: weakening or reversing the assumption that outsiders are relatively less informed (Noe, 1988; Nachman and Noe, 1994; Rahi, 1996; Fulghieri and Lukin, 2001; Axelson, 2007; Yang and Zeng, 2019), allowing for multiple sources of uncertainty (Fulghieri et al., 2020), allowing for Knightian uncertainty (Malenko and Tsoy, 2020).
- Security design from perspective of the competing, differentially informed suppliers of capital (Fishman, 1989; Inderst and Mueller, 2006; DeMarzo et al., 2005; Jansen et al., 2021; Liu and Bernhardt, 2021).

Ex-post asymmetric information and moral hazard

- Debt is optimal contract due to costly state verification (Townsend, 1979; Diamond, 1984; Gale and Hellwig, 1985).
- Performance-sensitive debt is optimal when outcomes can be perfectly observed and contracted upon (Manso et al., 2010; Chaigneau et al., 2021).
- Debt can discipline borrowers and induce effort provision but also risk-shifting (Innes, 1990; Hébert, 2018).
- Mechanism design aims to aligns incentives by designing abstract mechanisms, i.e., optimal contracts, which are then implemented using combinations of existing securities (DeMarzo and Sannikov, 2006; DeMarzo and Fishman, 2007; Biais et al., 2007).
- Mechanism design setups with ambiguity aversion (Miao and Rivera, 2016; Ling et al., 2021; Hansen, 2021; Szydlowski and Yoon, 2022).

Corporate Governance and the Allocation of Control Rights

Allocation of voting rights

- Mediates relationship between investors: corporate control contest perspective (Grossman and Hart, 1988; Harris and Raviv, 1988, 1989; Boot and Thakor, 2011; Burkart and Lee, 2008).
- Emerging issues: multi-class shares, markets for voting rights, increasing prevalence of proxy voting and concentration of voting power among few asset managers (Lewellen and Lewellen, 2022; Malenko and Malenko, 2023).

Transfer of control rights

- Mediates relationship between managers and investors: optimal allocation of control is state-contingent (Aghion and Bolton, 1992; Kaplan and Strömberg, 2003), debt has disciplinary role (Hart and Moore, 1998; Grinstein, 2006).
  - Governance in unfavorable states of the world i.e., assets insufficient to cover creditors' claims
    - Renegotiation makes contracts more contingent that they appear and can improve welfare (Hart and Moore, 1988; Huberman and Kahn, 1988; Gale, 1991; Hermalin and Katz, 1991; Aghion et al., 1994; Repullo and Suarez, 1998; Hackbarth et al., 2007).
    - Bankruptcy implications for debt design when bankruptcy is determined by applicable bankruptcy laws, the terms of a debt contract, as well as when bankruptcy and security design are jointly determined (Winton, 1995; Anderson and Sundaresan, 1996; Von Thadden et al., 2010; Antill and Grenadier, 2019).

Contingent allocation of cash-flow and control rights

- Contingent convertibles implement performance-contingent allocation of cash flow and control rights (Basak et al., 2020).
- Prevalent in venture capital, which is a double moral hazard environment (Schmidt, 2003; Repullo and Suarez, 2004; Hellmann, 2006).

SECURITY AND MARKET DESIGN INTERACTIONS

Instead of being taken as given, financial securities are derived as optimal mechanisms for overcoming various frictions between agents, leading to endogenous security designs and market structures.

- Market incompleteness makes the notion of optimal security design relevant and creates incentives to innovate (Allen and Gale, 1988, 1991; Gale, 1992; Madan and Soubra, 1991; Biais et al., 2021).
- Innovation and security design driven by incompleteness in markets for risk-sharing (Duffie and Jackson, 1989; Allen and Gale, 1990; Chowdhry et al., 2002) does not always improve welfare (Elul, 1995; Dow, 1998; Marin and Rahi, 2000) and raises questions regarding existence of seemingly redundant securities (Gorton and Pennacchi, 1993; Shen et al., 2014; Rostek and Yoon, 2021).
- Innovation driven by market segmentation includes introduction of new assets and integration of segmented markets (Acharya and Bisin, 2005; Rahi and Zigrand, 2009).
- Securities designed are not immune to the market structure in which trade occurs. Security design depends on market structure, and the two are jointly determined (Babus and Hachem, 2021, 2022).

FINANCIAL INTERMEDIATION

Contingent Capital

Refers to convertible debt securities that automatically convert to equity as FI's financial condition weakens. Popular designs include principal write-down bonds and contingent convertible bonds (CoCos).

- Numerous features along which security designs can vary:
  - Triggers based on book- or market-based measures, single vs dual triggers, equity triggers based on market cap vs share price (McDonald, 2013; Glasserman and Nouri, 2012; Pennacchi, 2019).
  - Conversion to common or preferred equity, to fixed or a variable number of shares, at stock's current market price or pre-specified price (Flannery, 2005; Coffee, 2010; Pennacchi et al., 2014).

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- Concerns over risk-shifting, equity holders wealth transfers, market manipulation (Berg and Kaserer, 2015; Albul et al., 2015; Sundaresan and Wang, 2015; Himmelberg and Tsyplakov, 2020; Hilscher et al., 2022).
- Contingent capital implementations have triggers based on book-value capital ratios, which raises concerns regarding timely conversion, and evidence suggests they do not favor debtholders (Berg and Kaserer, 2015; Fiordelisi et al., 2020; Goncharenko et al., 2021).

Securitization

Pooling and tranching involves creating pools or portfolios of financial assets and selling claims to cash flows generated by the pool of assets to various categories of investors.

- Optimality of combining pooling and tranching (DeMarzo, 2005; Ortner and Schmalz, 2019; Garmaise, 2001; Noe et al., 2006).
- Tranching enables creation of low-risk, highly liquid securities, with varying degrees of sensitivity to seller's private information (Gorton and Pennacchi, 1990; Boot and Thakor, 1993; DeMarzo et al., 2021; Hennessy and Jankowitsch, 2016).
- Tranche retention choices signal sellers' private information about the quality of the pool (DeMarzo and Duffie, 1999; Daley et al., 2020; 2023), and tranching and retention choices can mitigate moral hazard (Fender and Mitchell, 2009; Hartman-Glaser et al., 2012; Chemla and Hennessy, 2014).
- Allocation of control rights to various tranches (Riddiough, 1997; Riddiough and Zhu, 2016).

COMPLEX SECURITY DESIGNS

Supply of complex security designs

- Optimal response of security designers competing for market power and profits (Carlin, 2009; Carlin and Manso, 2011).
- Evidence that complex securities do not seem to be designed to benefit consumers (Henderson and Pearson, 2011; Vokata, 2021; Ghent et al., 2019).

Demand for complex security designs

- Cater to retail investors' yield-seeking behavior (Célérier and Vallée, 2017), their demand for safe assets or loss aversion (Coval et al., 2009), behavioral biases such as salient thinking (Vokata, 2023), preferences of suppliers of capital (Grundy and Verwijmeren, 2018).

FINTECH

Corporate financing interactions

- Security tokens have brough about alternative forms of financing through ICOs (Bakos and Halaburda, 2019; Gryglewicz et al., 2021; Chod and Lyandres, 2021).
- Smart contracts enable commitment to predetermined rules and can eliminate in an automated and conflict-free way some contracting frictions like the need for costly verification, enforcement, or the risk of renegotiation (Tinn, 2017; Cong et al., 2022; Catalini and Gans, 2018; Malinova and Park, 2018).

Corporate governance interactions

- Decentralized consensus mechanism replaces the need for trust and centralized leadership.
- Emergence of Decentralized Autonomous Organizations (DAOs) with rules of governance represented by collection of smart contracts and executed when required (Karjalainen, 2020).
- Shifting governance to the blockchain raises questions about blockchain governance. Evidence challenges the idea that PoW blockchain is truly decentralized (Makarov and Schoar, 2021).

Trading and financial markets interactions

- Financial securities can be digitally represented, making possible the use of smart contracts as the basis for transference.
- Potential to reduce or eliminate inefficiencies and frictions that currently exist in relation to storing, recording, transferring, and exchanging digital assets (Mills et al., 2017).
- Market based on token systems that resolves settlement risk (Lee et al., 2021a, b).
- Decentralized consensus entails distributing all transaction information (Cong and He, 2019; Malinova and Park, 2017).

SUSTAINABLE FINANCE

Public and hybrid solutions for financing sustainability

- Social welfare services are typically funded by governments.
- Social Impact Bonds (SIBs): public administration contracts provision of a social service of interest to external service provider (non-profit), with funding being provided by private investors (Rangan and Chase, 2015; Wong et al., 2016; Pauly and Swanson, 2017; Tortorice et al., 2020).
- Designed to incentivize investors to provide funding for projects addressing social challenges (return to investors increases with the social performance of the project).

Market-based solutions for financing sustainability

- Equity markets can induce change through:
  - Corporate governance channel, e.g., engagement (Hart and Zingales, 2017; Broccardo et al., 2022).
  - Cost of capital channel e.g., divestment, tilting (Heinkel et al., 2001; Pastor et al., 2020; Edmans et al., 2022).
- Conditions for impact when financing is provided by heterogenous investors i.e., socially-motivated and financially-motivated investors (Chowdhry et al., 2019; Oehmke and Opp, 2020).
- Debt markets mobilize capital through instruments designed to incentivize firms to address climate and sustainability challenges (investors forgo returns). Security designs can be categorized as:
  - Project-based non-contingent contract designs, e.g., green bonds and loans (Ehlers and Packer, 2017; Baker, Bergstresser et al., 2022; Flammer, 2021; Fatica and Panzica, 2021).
  - Outcome-based contingent contract designs, e.g., sustainability-linked bonds and loans (Loumioti and Serafeim, 2022; Kim et al., 2023; Du et al., 2022; Kölbel and Lambillon, 2022).
- Trade-offs faced by firms when choosing between these green debt contract designs (Barbalau and Zeni, 2022).
- Carbon-contingent security design can be equivalent to a carbon tax (Allen et al., 2023).
- Evidence on impact is mixed and concerns exist about counterproductive implication of sustainable investing. Investors may not internalize aggregate welfare implications of their actions (Green and Roth, 2021; Oehmke and Opp, 2020; Bisceglia et al., 2022; Gupta et al., 2022; Huang and Kopytov, 2023; Hartzman and Shue, 2023).

HEALTHCARE FINANCE

Solutions for closing funding gap:

- Megafund approach employs securitization to pool biomedical projects into single financial vehicle or fund which is to issue tranches of debt and equity (Stein and Lo, 2012).
- Extensions of the megafund concept: government guarantees and assistance (Fernandez et al., 2012; Lo and Thakor, 2023), role of dynamic leverage as a function of the clinical phases of projects in the portfolio (Montazerhodjat et al.,

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2016), correlation between phase transitions in drug development projects (Lo and Siah, 2020), applications to disease-specific portfolios of drug targets (Lo and Thakor, 2021; 2023).
- FDA Hedges are essentially insurance contracts that pay off upon the failure of individual drug projects to gain FDA approval (Jørring et al., 2017).
- Optimal financing for R&D-intensive firms implemented using put options (Lo and Thakor, 2021).

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