DEPARTMENT
OF ECONOMICS

Essays in Financial Economics

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Thesis submitted for assessment with a view to
obtaining the degree of Doctor of Economics
of the European University Institute

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Department of Economics

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Abstract

This thesis contributes to the literatures on socially responsible investment and banking regulation. In the first paper, I ask how socially responsible investors (SRI) should allocate their capital to influence firm behaviour in the framework of a vertical production economy. This simple production network opens up the additional question of whether supply-chain policies should be imposed. The optimal strategy depends on the amount of funds available to the SRI, relative to the value of the economy. When SRI wealth is low, it is optimal to target the sector with the lowest effective reduction costs, and to refrain from supply-chain policies. However, when SRI wealth is sufficiently high, it becomes optimal to target downstream firms and prescribe a "green" supply chain policy. This result arises because supply chain policies incentivize upstream firm owners to turn green, but only if a critical mass of downstream firms imposes such requirements.

The second paper analyzes the effects of tightened bank capital requiremens on lending in a dynamic setting. It is motivated by empirical observations of temporary rather than long run lending declines and sluggish increases of equity levels. I provide an overview over the set of distinct mechanisms that may rationalize this finding by driving a wedge between the costs of external and internal equity. The considered demand-side frictions are direct issuance costs, adverse selection, debt overhang and control dilution reluctance, while I also discuss the potential role of inelastic short-run equity supply. While the theoretical merits of and empirical evidence on these mechanisms' core premises tend to be strong for the banking sector, empirical results about their effects on equity issuances and interactions with capital regulation are more mixed and scarce. I discuss interactions between these frictions and policy recommendations that depend not only on their joint significance but also on the contribution of the single components of these "flow costs of equity".

To the Via Trieste Running Crew.

Contents

Chapter 1: Socially Responsible Investment in Supply Chains

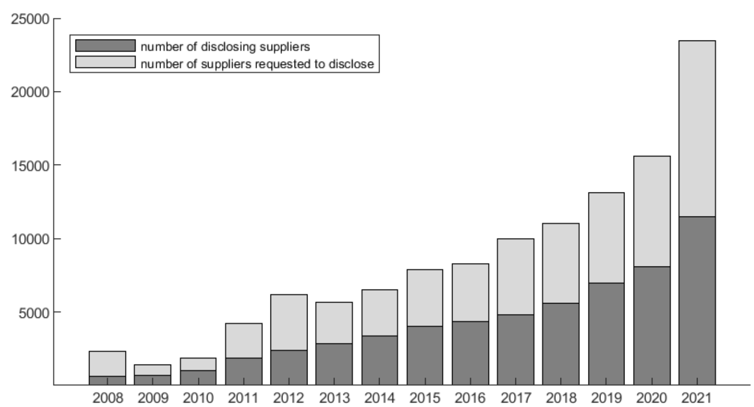
1.1 Introduction

One of the core questions in both the theory and practice of sustainable finance is the question of impact: how, possibly in the presence of constraints on financial return or risk, should scarce capital of socially motivated investors be allocated to maximize social impact. In the context of climate change and greenhouse gas (GHG) emissions, the initial focus in the academic literature has been on firm-level emissions (e.g. Green and Roth 2021, Oehmke and Opp 2022). And also in practice, data disclosure and reduction efforts started with a focus on emissions of direct firm-level activities. Such operational emissions are defined as scope 1 emissions (GHG Protocol 2004).

However, these direct emissions can be small relative to so-called scope 2 and 3 emissions. The former includes emissions from the generation of electrity used for production, while the latter is even broader and includes emissions from upstream input production and downstream product usage. The non-profit Carbon Disclosure Project (CDP) calculates that, in the set of firms who participate in their initiative, GHG emissions from acitivites in these companies' supply chains are on average 11.4 times higher than the companies' scope 1 emissions (CDP 2022).

From this follows that there are potentially sizeable effects of imposing supply-chain policies. Instead of directly targeting highly polluting upstream firms, investors with emission reduction goals may enforce strong sustainability requirements on the procurement policy of more downstream firms. Indeed, the GHG Protocol (2011) offers best practice advice for managing supply chain emissions, and CDP (2022) provides evidence for rising adoption of emission disclosure requests targeted at firms' suppliers. As is shown in Figure 1.1, this rising interest of downstream producers in their scope 3 emissions is accompanied by an uptake in the number of upstream firms responding to these requests. While overcoming information issues is not equivalent with reducing emissions, it is a necessary condition for efficiently doing so.

In this paper, abstracting from information issues, the research questions I am raising are twofold: where in the production network should socially responsible investors intervene to create the largest possible impact? Also, under what conditions is it optimal to impose supply chain policies, i.e. requirements on suppliers' emissions?



Source: Carbon Disclosure Project (2022).

Figure 1.1: Number of suppliers disclosing carbon emissions through CDP.

I find that this depends on the size of the pool of funds that is available for externality reduction, relative to the total value of the economy. Only when the SRI is able to invest a sufficiently big pool of funds does supply-chain policy become effective. But when it does, it will also be optimal, since it will give rise to a multiplier effect: all firms are green as a consequence of the investments, but the investor is not paying for upstream firms' greening costs. On the other hand, when SRI funds are sufficiently scarce, the supply chain policy will be prohibitively costly, and it will be optimal to only target firm-level scope 1 emissions.

These findings are relevant because they imply that imposing supply chain policies becomes less costly when this is done by more firms: once a “critical mass” of supply-chain imposing downstream firms can be reached, suppliers are incentivized to green their technology through market mechanisms. This underlines the importance of investor alliances to share costs and avoid coordination failure. It also yields useful insights for policy makers considering the introduction and design of supply chain regulations like the Supply-Chain-Act in Germany, passed in 2021, or the EU Corporate Sustainability Due Diligence Directive. These oblige firms above a certain size to ensure that their supply chains meet certain standards regarding environmental impacts and human rights.

The paper is structured as follows: after a discussion of the related literature in section 1.2, I will introduce the baseline vertical production model in section 1.3, before introducing socially responsible investment in section 1.4. There, I will already introduce a simple firm-level greening policy, before discussing supply-chain policies in section 1.5. Section 1.6 concludes.

1.2 Literature

This paper is located at the intersection of two literatures, socially responsible investment and production networks.

Investor objectives. The literature on socially responsible investment has obtained growing attention in recent years, as a likely reflection of the surge in real-world “green investments”. It remains to be seen to what extent these funds are indeed driven by motives other than financial returns. Finding an answer to this question is the focus of a growing empirical finance literature. Three different motivations have been pointed to as possible drivers of sustainable investments: financial motives, the wish to hold investments that are “aligned” with ones values[1], and the wish to have a real-world impact (2DII 2020).

[1] An example of this would be to hold a portfolio of shares in non-polluting firms in order to not feel

Barber et al. (2021) find evidence for impact motives in a comparison of classical and impact-oriented venture-capital funds. Bauer et al. (2021) observe the votes of the members of a pension fund granting them a say on sustainability policy. They find that a majority of members support firm engagement based on sustainability goals, even when this is expected to decrease financial returns. Heeb et al. (2022) conduct a field experiment to assess how investments' impact levels affect retail investors' willingness to pay (WTP) for sustainable investments. They find that WTP increases in impact, but that it strongly depends on the set of available investment choices. The authors interpret this as an element of "warm glow" preferences (Andreoni 1990), which falls into the motive category of value alignment.

In this paper, I take as given that there is an investor who internalizes the overall level of pollution caused by production. This focus on total externalities in the economy, which is referred to as "broad mandate" by Oehmke and Opp (2022), captures the impact achievement motive. I argue that this is the more relevant motive in the given context, since I consider (coalitions of) big investment funds, which are likely to be more professional in managing assets in a way that creates actual impact. In any case, while it may be interesting to analyze the effects of value aligned portfolios, the focus of this paper is how investments should be allocated in order to achieve the biggest possible impact.

Impact mechanisms. In practice, the optimal allocation of socially responsible capital will depend on the mechanism through which impact can be achieved best, and at all. This is an open question. The main focus of the debate has been about the relative effectiveness of engagment with firms' managements, in contrast to investment or divestment strategies which aim to affect firms' financing costs. Kölbel et al. (2020) provide a review of the literature and find that an impact of engagement is supported by empirical studies, while capital allocation results are documented less thoroughly. The theoretical paper of Broccardo et al. (2022) comes to the conclusion that engagement is more effective when the majority

associated with pollution. Under this motive, investors do not necessarily consider whether their purchase and position of these assets has any effect on real-world pollution outcomes.

of investors is socially oriented, while divestment is more effective when that is not the case.

In my model, I do not model firms' capital needs, and impact is achieved through firm control, an extreme form of engagement. I assume that control is acquired by one big socially responsible investor, which potentially represents a coalition of smaller sustainability-focused investment funds. As explained in Oehmke and Opp (2022), this assumption shuts off the coordination problem which would arise otherwise because externality reduction is a public good for SRI with a broad mandate. In practice, successful investor coalitions do exist in such contexts, as documented in Dimson et al. (2021). They find that success rates for a coordinated engagements are highest under a two-tier strategy, in which a lead investor is supported by other investors.

Optimal allocation of SRI funds. Given that some investors are willing to pay for externality reduction, some papers study how they should allocate their funds to maximize their impact. Green and Roth (2021) build a framework in which financially and socially motivated investors compete. They find that value alignment is outperformed in impact terms by other investment strategies.

Similarly, Oehmke and Opp (2022) establish that a broad mandate is necessary for SRI to have social impact, and they find that socially and financially motivated investors are complementary in increasing social welfare. Their mechanism relies on the threat of more severe pollution when financially motivated investors are present, which increases SRIs' willingness to pay for mitigation. Additionally, they derive a social profitability index, which indicates which investments should be made to maximize impact when socially investible capital is scarce. The optimal investment strategies that I derive in my model as a function of SRI wealth can also be interpreted as such an index. However, in my model, the target order of firms depends on investor wealth, which is not the case in their model. This difference arises because my model features market interactions between firms, which affect the cost and benefit consideration. In contrast, firms in their model only compete for financing, but do not interact on markets.

Gupta et al. (2022) also consider a broad mandate, but their setup is a dynamic model with search frictions. This allows them to study the dynamic adjustment of stock prices, production and the externality to the rise of social investment motives. They find that SRI may lead to a slow-down of firms' transition towards greener production due to stock price expectations: current owners of firms that produce severe externalities may anticipate socially motivated investors' high willingness to pay for their polluting firms in the future. This strategic element is not present in my model.

Chowdhry et al. (2019) study a framework with moral hazard of entrepreneurs in pursuing the social outcome. Profit-motivated and SRI investors can provide joint financing to alleviate this agency problem. They find that the optimal ownership structure depends on the value of the social output. My model does not feature moral hazard in the achievement of social goals, since I assume that the technology and supply-chain choices of the SRI are binding for the firm manager.

Unlike these papers, I explicitly model the market interaction between firms horizontally and vertically. As a result, there can be spillover effects from the intervention in one part of the economy into the other. This can affect the cost of intervening simultaneously at a different point, and in can also affect the overall impact of the intervention.

Shareholder welfare. This paper is related to the growing literature on shareholder welfare maximization, e.g. Hart and Zingales (2017) since socially motivated investors value a common good besides just shareholder value. Note that this is distinct from the concept of stakeholder value maximization, e.g. in Magill et al. (2015), since the former focuses solely on shareholders, while the latter examines the merits of considering also other stakeholders' outcomes in the firm objective.

In a related strand of literature on the corporate provision of public goods, e.g. Morgan and Tumlinson (2019), firms have a comparative advantage over other agents to provide a public good. This is arguably the case in practice for GHG emissions. In my model, a reduction of pollution is exclusively achieved at its origin, by exchanging the polluting technology for a clean one.

Environmental regulation. While not modeling the effects of environmental policy explicitly, this paper provides useful preliminary insights. In particular, the supply chain policy analyzed in this paper is imposed by investors instead of regulators. While its effects conditional on implementation do not depend on the source of the policy, investor welfare is likely to differ from social welfare even for socially motivated investors. Regulators' and investors' incentives to impose a supply chain policy are therefore likely to differ. In the context of global value chains it will be important to discuss regulators' objectives, which may also differ from those of a global social planner.

Another type of environmental regulation is carbon pricing, as examined by Heider and Inderst (2023) in a classical Holmstrom and Tirole (1997) model of financially constrained firms. As in my model, their setup allows to study the effects of environmental policies when firms compete in goods markets. They find that in the presence of financial constraints, the optimal price on carbon may be higher than without such frictions. The reason for this result is that the resulting reduction of production and increase in product prices implies a positive pecuniary externality for greener firms. The green supply and demand effects found in my paper do not result from carbon pricing but from investor-imposed constraints on technology and demand. They are internalized by the investor, but constitute pecuniary externalities from the perspective of individual firm managers. While my model is richer with regard to the vertical market structure, the model by Heider and Inderst (2023) is richer with regard to the welfare analysis they provide.

Production networks. Following the work by Acemoglu et al. (2012), a macroeconomics literature has developed which studies the propagation of shocks through the economy, e.g.

Baqaee (2018). My model is related to this literature in that it also analyzes spillovers between sectors, in the framework of a strongly simplified network with two perfectly vertical sectors. In contrast to the effects of exogenous firm-level shocks, my model considers the effects of policy interventions, which opens up the additional question of where best to intervene in the network. This question is also raised by Galeotti et al. (2020), who examine how a social planner intervenes when agents interact with each other strategically in a network.

The paper by Pankratz and Schiller (2021) deals with both climate change and global value chains. Their paper considers the effect of climate change on supply chains, and examines changes in these chains as an adaptation measure. In contrast, I model how mitigation measures can be optimally employed in supply chains.

1.3 Baseline model

We are considering a static partial equilibrium model. There are four types of goods in the economy: besides labour and money, which will be the numeraire, there are two types of produced goods, intermediary and final. There are three types of agents: workers, consumers and investors.

Each investor owns exactly one firm in one of two sectors, upstream or downstream. Each sector consists of a mass one of firms that interact in monopolistic competition following Dixit and Stiglitz (1977). Firms in the upstream sector employ labour provided by the representative worker to produce intermediary good varieties. Downstream firms employ intermediary good varieties to produce final good varieties. The latter are consumed by the representative consumer. Labour, upstream and downstream goods are traded against money.

Consumers. The representative consumer is endowed with financial wealth W_c. Taking the output price p_{2i} of any downstream variety i as given, she demands amounts c_{2i} of the varieties to optimally assemble them into the aggregate consumption good, c_2. Her maximization problem is

$$\max_{c_2,\{c_{2i}\}} c_2$$

$$\text{s.t.} \quad c_2 = \left(\int_{i=0}^{1} c_{2i}^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}, \quad \epsilon > 1 \tag{1.1}$$

$$W_c \geq \int_{i=0}^{1} p_{2i} c_{2i} di \tag{1.2}$$

where (1.1) is the constant elasticity of substitution (CES) consumption aggregation function, and (1.2) is the budget constraint.

This problem can be solved by following a two-stage procedure, in which the first step is to choose variety demands to minimize expenditure given c_2. The second step is to choose c_2 to maximze utility. It yields variety and final demand functions

$$c_{2i} = \left(\frac{p_{2i}}{P_2} \right)^{-\epsilon} c_2 \tag{1.3}$$

$$c_2 = \frac{W_c}{P_2} \tag{1.4}$$

where P_2 is the consumer price index which captures the unit cost of the final consumption good and can be derived to equal

$$P_2\Big(\{p_{2i}\}_i\Big) \equiv \left(\int_{i=0}^{1} p_{2i}^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}} \tag{1.5}$$

Downstream. Downstream sector firm i takes input prices p_{1j} as given for all intermediate varieties j. It anticipates consumer demand as a function of its price choice, and chooses its output price and input schedule to maximize profits,

$$\pi_{2i} = \max_{p_{2i},\{x_{ij}\}_j,y_{2i}} p_{2i}y_{2i} - \int_{j=0}^{1} p_{1j}x_{ij}dj$$

$$\text{s.t. } y_{2i} = \left(\int_{j=0}^{1} x_{ij}^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}} \tag{1.6}$$

$$y_{2i} = y_{2i}(p_{2i}) \tag{1.7}$$

where (1.6) is the CES production technology.

Combining equations (1.3) and (1.4) yields the consumer demand for variety i as a function of p_{2i} and P_2. However, its individual effect on the consumer price index P_2 is zero. Therefore, the demand function that is faced by firm i in setting its optimal price is

$$y_{2i}(p_{2i}) = p_{2i}^{-\epsilon}\delta_2 \tag{1.8}$$

$$\delta_2 \equiv P_2^{\epsilon-1}W_c$$

with δ_2 being a demand factor that the firm takes as given.

Following the two-step procedure as in the consumer problem, we can derive optimal input demand functions conditional on output level y_{2i},

$$x_{ij} = \left(\frac{p_{1j}}{P_1}\right)^{-\epsilon} y_{2i} \tag{1.9}$$

$$P_1\Big(\{p_{1j}\}_j\Big) \equiv \left(\int_{j=0}^{1} p_{1j}^{1-\epsilon}dj\right)^{\frac{1}{1-\epsilon}} \tag{1.10}$$

where the downstream producer price index P_1 measures the unit costs of downstream production. The optimal price is set at a markup over the downstream producer price index

$$p_{2i} = P_1\mu \tag{1.11}$$

$$\mu \equiv \frac{\epsilon}{\epsilon-1}$$

where the Lerner index μ is the usual measure of market power.

Workers. The representative worker supplies labour $\bar{l} = 1$ inelastically at the nominal wage w, which will adjust to clear the labour market.

Upstream. Upstream firm j employs a linear technology $y_{1j} = l_j$. Taking wage w and the downstream demand schedule as given, it chooses price p_{1j} to maximize profits

$$\pi_{1j} = \max_{p_{1j}, y_{1j}} \quad p_{1j} y_{1j} - w y_{1j}$$
$$\text{s.t.} \quad y_{1j} = y_{1j}(p_{1j})$$

Combining (1.8) – (1.11) and noting that downstream firms are symmetric, we obtain downstream demand[2] for input j

$$y_{1j}(p_{1j}) = p_{1j}^{-\epsilon} \delta_1 \tag{1.12}$$
$$\delta_1 \equiv \mu^{-\epsilon} \delta_2$$

The optimal price will be set at markup over wage, which is the upstream producer price

$$p_{1j} = \mu w$$

Equilibrium. Labour market clearing

$$1 = \int_{j=0}^{1} y_{1j} dj$$

[2]Note that here, the downstream unit price P_1 cancels from the demand function $y_{1j}(p_{1j}) = (\frac{p_{1j}}{P_1})^{-\epsilon}(\frac{P_1 \mu}{P_2})^{-\epsilon} \frac{W_c}{P_2}$ due to the assumption that elasticities for consumption and downstream variety aggregation are the same. Thus, the substitution and income effect from a change in the downstream PPI always perfectly cancel for upstream firms.

gives the equilibrium wage

$$w = \frac{W_c}{\mu^2}$$

and dropping the subscripts i and j since firms are symmetric within sector, we obtain the equlibrium production, prices and profits

$$\begin{aligned} y_1^* &= y_2^* = 1 \\ p_1^* &= P_1 = w\mu \\ p_2^* &= P_2 = w\mu^2 \\ \pi_1 &= \frac{W_c}{\epsilon\mu} \\ \pi_2 &= \frac{W_c}{\epsilon} \end{aligned} \tag{1.13}$$

where the classical double marginalization result $\pi_2 > \pi_1$ is obtained.

1.4 Firm-level policy

Externality. Now assume that firms in sector $k = 1, 2$ inflict a negative externality of $\phi_k > 0$, per unit of production, on a good which is valued by some agent in the economy. At financial fixed cost κ_k per firm, this externality can be reduced to 0.

Investors. Besides the financially motivated investors (F-investors) that are endowed with the firms, there is now an additional investor, who is endowed with financial capital W. We call this investor a "socially responsible" investor (SRI) because she internalizes a fraction λ of the total externality produced in the economy. She can acquire firms' shares to obtain control over firms' policies and potentially reduce the externality.

Following Oehmke and Opp (2022), these assumptions on the SRI can be interpreted as those of a broad mandate and coordination. The term broad mandate describes the assumption that socially responsible agents care about the total externality, instead of just a subset of the externality that can be attributed to themselves in any way. As a result, externality reduction is a common good among socially responsible investors and any other agent who is affected by the externality. From this follows an incentive to free-ride on others' externality reduction efforts. Here, assuming that there is just one socially responsible investor, we are shutting off the resulting coordination problem, since it is not the focus of this paper.

Control. Firms' financial and control rights are separated, which is not without loss of generality as will be discussed later. For simplicity, we also assume that the control share is indivisible. This assumption is without loss of generality if we assume majority control of firms: under divisible shares, the investor would just buy exactly half of the shares plus an infinitesimal share, but the price would scale accordingly.

The SRI has all the bargaining power: she can make a take-it-or-leave-it offer to F-investor ki to buy that share at price p^e_{ki}.

Profit maximization. Every firm is run by a manager who maximizes firm profits conditional on the firm owner's choice to turn the firm green or not. While firm-level profit maximization is a standard assumption, note that it constitutes an agency problem in the given setup because the investor will be holding a portfolio of firms, and would therefore prefer managers to maximize portfolio value.[3,4]

SRI choices. Since firms are identical within-sector, the investor chooses masses (m_1, m_2) of firms to buy and "turn green". Since she has all the bargaining power, all offers she makes will keep F-investors at their outside option of not accepting the offer,

$$p^e_k = \max\Big\{0, \pi^B_k - \Big(\pi^G_k - \kappa_k\Big)\Big\} \tag{1.14}$$

[3] See e.g. Azar and Vives (2021) for a model that elaborates on the potential implications of common ownership and portfolio value maximization.

[4] This would matter to the SRI despite the assumption that financial and control rights are separated. The reason is that one firm's production decisions affect the other firms' profits and therefore the share price.

It will be sufficient to consider policies where all firms that the SRI buys are also turned green. The reason is that when firms would turn green anyways, or are kept brown, the price is zero and a purchase will be inconsequential.

Instead of buying firm control shares, the SRI can invest her financial capital W into buying a bond b with a riskless return of 1. To analyze the case in which socially responsible capital is exogenously scarce, we will assume that the investor cannot borrow, $b \geq 0$.

Firm-level policy. Consider the case that upon buying a firm, that firm's production process is turned green, but input decisions are not conditioned on other firms' greening decisions.

Since the greening cost is a fixed cost, input and production decision are unaffected by the acquisition of the firm. Therefore, for $k = 1, 2$,

$$y_k^B = y_k^G = \bar{l} = 1$$
$$\bar{\pi}_k \equiv \pi_k^B = \pi_k^G$$

so that the share price is always strictly positive, $p_k^e = \kappa_k > 0$. The investor chooses masses of green firms (m_1, m_2) to maximize the sum of her financial utility, and the total production externality, weighted by λ:

$$\max_{m_1, m_2} \underbrace{W - m_1\kappa_1 - m_2\kappa_2}_{\text{financial utility}} - \lambda\Big[\underbrace{\phi_1\Big(1 - m_1\Big) + \phi_2\Big(1 - m_2\Big)}_{\text{externality}}\Big]$$
$$\text{s.t.} \quad W - m_1\kappa_1 - m_2\kappa_2 \geq 0$$
$$m_1 \geq 0, 1 - m_1 \geq 0, m_2 \geq 0, 1 - m_2 \geq 0$$

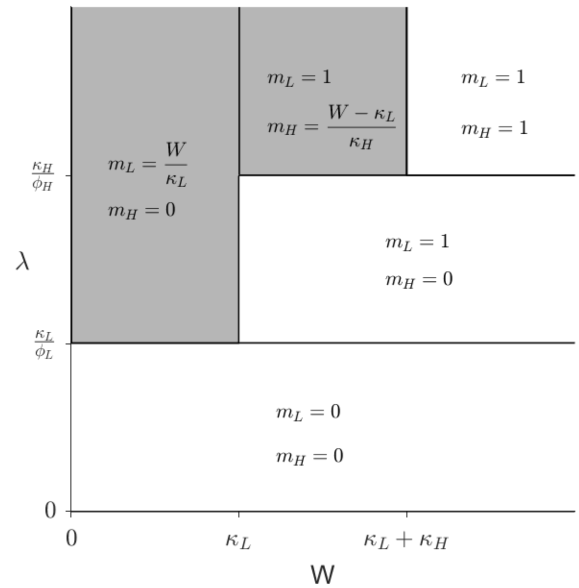


Figure 1.2: Optimal acquisition of firms under firm-level greening.

The solution of this problem is illustrated in Figure 1.2. Here and also in the following sections, denote with

$$L \in \{1, 2\}: \text{ the sector with the lower cost-to-benefit ratio } \frac{\kappa_k}{\phi_k}$$

and with H the other sector. If $\lambda > \frac{\kappa_L}{\phi_L}$, then the SRI will want to take control of as many firms in L as she can. Only once she has sufficient resources to acquired all of the L firms, and only if $\lambda > \frac{\kappa_H}{\phi_H}$, will she turn to firms in the H-sector. The grey areas are those in which the investor's borrowing constraint is binding.

Note that if the financial and control rights were not separated, the share price offered by the investor would be $p_k^e = \max\{\bar{\pi}_k, \bar{\pi}_k - \kappa_k\}$, which is always $\bar{\pi}_k$. Therefore, the investor's decision of which firms to target first would additionally depend on the profitablity of firms in that sector, and from (1.13) on W and ϵ. This is not the case under separated rights.

For now, and without loss of generality, set $\lambda = 1$. In addition, let the following assumption hold:

ASSUMPTION 1 $\kappa_k < \phi_k, \; k = 1, 2$, *i.e. in both sectors the externality exceeds greening costs in the baseline economy*

This assumption implies that under the firm-level policy, the investor always prefers to green all firms in both sectors. So depending on W, the optimal intervention is in one of the upper regions in Figure (1.2) and the borrowing constraint is binding as long as $W < \kappa_1 + \kappa_2$.[5] The reference to the baseline economy is necessary because in the case of the supply-chain intervention discussed next, firm-level output is not always 1, so that the externality produced by a firm is not always ϕ_k. In addition, we restrict attention to that part of the parameter space for which the following assumption holds:

ASSUMPTION 2 $\kappa_k < \bar{\pi}_k, \; k = 1, 2$, *i.e. in both sectors the baseline profits net of greening costs are positive.*

This will imply that firm profits have to be sufficiently large relative to greening costs. From (1.13) it therefore also means that the elasticity ϵ must not be too large relative to consumer wealth W_c. In other words, we are not considering a market that tends to perfect competition, since such a market would imply zero market profits and therefore negative profits net of fixed greening costs.

1.5 Supply-chain policy

Now, we examine the case in which input decisions are conditioned on suppliers' greening decisions in the sense that green downstream firms only buy from green upstream firms.

The F-investor of an unacquired firm in sector k turns it green if $\pi_k^G - \kappa_k > \pi_k^B$, which could never occur under the firm-level intervention. We will denote with $\tilde{m}_k$ the mass of firms in sector k that are not acquired but turn green regardless, and the total measure of

[5] In the partial equilibrium setup studied, it is not clear what this assumption implies for the socially optimal technology choice. The reason for this is that it is not clear how the deadweight monetary greening cost affects social welfare.

green firms with $M_k = m_k + \tilde{m}_k$.

To solve for the optimal decision of the SRI, three steps will be necessary. Firstly, we solve for the market equilibrium conditional on (M_1, M_2). Secondly, we find the endogenous greening responses $(\tilde{m}_1, \tilde{m}_2)$ conditional on SRI choices (m_1, m_2). Finally, we solve for the investor's optimal choice of (m_1, m_2), in anticipation of the greening and production responses derived in the previous two steps.

1.5.1 Market equilibrium given (M_1, M_2).

Consumers. The consumer problem is unchanged. She demands from all downstream firms, green and brown, since to her only prices matter.[6] As before, equation (1.8) is the consumer demand for downstream variety i as a function of its price.

Downstream. Green downstream firms now only buy from the set of green upstream firms, G_1. As a result, they have weakly higher unit costs than brown ones. This is because fewer input varieties lead to lower production efficiency due to the "love of variety" feature of in the Dixit-Stiglitz model of monopolistic competition.[7]

$$\begin{aligned} P_1^G &\equiv \left(\int_{j \in G_1} p_{1j}^{1-\epsilon} dj \right)^{\frac{1}{1-\epsilon}} \\ &\geq \quad \left(\int_{j=0}^{1} p_{1j}^{1-\epsilon} dj \right)^{\frac{1}{1-\epsilon}} \equiv P_1^B \end{aligned} \tag{1.15}$$

These higher input costs will be reflected in output prices, since firms set prices at markup μ.

[6]Extending the model to allow for socially responsible consumers who only demand green products would introduce excess demand also for green downstream firms. Again, results would differ depending on whether these consumers take the entire supply chain emissions into account or only the first tier, i.e. downstream emissions.

[7]This term describes the property of the CES technology

$$y = \left(\int_{i=0}^{M} x_i^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}, \;\; \epsilon > 1$$

to be increasing in M (if all inputs are demanded and holding total inputs $\int_{i=0}^{M} x_i di$ constant). For example, if $x_i = x/M \, \forall i$, $y = xM^{1/(\epsilon-1)}$.

So consumer demand for green varieties will be lower than for brown ones.

Upstream. Green inputs are demanded by both downstream types, while brown inputs are only demanded by brown downstream firms:

$$y_{1j}(p_{1j}) = \begin{cases} p_{1j}^{-\epsilon}\delta_1^G, & \delta_1^G \equiv \mu^{-\epsilon}\delta_2 & \text{if } j \in G_1 \\ p_{1j}^{-\epsilon}\delta_1^B, & \delta_1^B \equiv \mu^{-\epsilon}\delta_2(1-M_2) & \text{if } j \notin G_1 \end{cases}$$

Therefore, at any price p_{1j}, demand for a brown firm is a fraction $1 - M_2$ of that for a green firm.[8] Both types still set

$$p_{1j} = \mu w \tag{1.16}$$

The intuition for this is that their demand functions differ only in levels. But crucial for the marginal cost-benefit consideration

$$y_{1j}(p_{1j}) + [p_{1j} - w]y'_{1j}(p_{1j}) = 0$$

is the price elasticity of demand, which is equal to ϵ for both types. As a result, green firms' profits (before greening costs) will be higher, but only due to the larger quantity sold, not because of setting a higher price.[9]

Market integration $\hat{M}$. Inserting input prices (1.16) into the green downstream producer prices yields $P_1^B = w\mu$ and $P_1^G = w\mu M_1^{\frac{1}{1-\epsilon}}$. Using these, we obtain the consumer price index

$$\begin{aligned} P_2 &= \mu(M_2 P_1^{G\ 1-\epsilon} + (1-M_2)P_1^{B\ 1-\epsilon})^{\frac{1}{1-\epsilon}} \\ &= w\mu^2(M_2 M_1 + 1 - M_2)^{\frac{1}{1-\epsilon}} \end{aligned}$$

[8] The sharpness of this result relies on the assumption of equal elasticities in the two sectors because only then do producer price indexes P_1^G, P_1^B cancel from factor demand functions.

[9] Note that this would not change if we allowed upstream firms to differentiate prices conditional on buyer characteristics.

so that the consumer price index is decreasing in the term

$$\hat{M}(M_1, M_2) \equiv 1 - M_2(1 - M_1) \quad \in [0, 1]$$

This term measures to what extent the market is integrated, as opposed to segmented, based on the greening and supply-chain policies. Market integration is also a measure of production efficiency in the vertical economy: the more integrated the economy, the more efficiently the final and intermediate goods are assembled. Note that a decrease in market integration through greening policies has inflationary effects, since a decrease in goods meets constant nominal consumer spending.

As $M_1 \to 1$, the inefficiency disappears for any M_2: when all upstream firms are green, all downstream firms, irrespective of green or brown, buy from all upstream firms. As $M_2 \to 0$, the production inefficiency disappears for any M_1. The reason is that all downstream firms are brown and thus demand all upstream firms' varieties. Finally, note that when $M_1 = 0$ and $M_2 = 1$, market integration $\hat{M} = 0$. In that case, there is a complete mismatch of produced and demanded goods, since exclusively brown inputs are supplied, but only green inputs are demanded.

Equilibrium. Again imposing labour market clearing,

$$\begin{aligned} 1 &= M_1 y_1^G + (1 - M_1) y_1^B \\ &= y_1^G \Big[M_1 + (1 - M_1)(1 - M_2) \Big] \\ &= y_1^G \hat{M} \end{aligned}$$

we find that the equilibrium wage is the same as in the baseline economy, $w = \frac{W_c}{\mu^2}$ and therefore does not depend on M_1, M_2. Equilibrium production and profits are

$$\begin{aligned} y_1^G &= \frac{1}{\hat{M}}, & y_2^G &= \frac{1}{\hat{M}} M_1^{\frac{\epsilon}{\epsilon-1}} \\ y_1^B &= \frac{1}{\hat{M}}(1-M_2) & y_2^B &= \frac{1}{\hat{M}} \\ \pi_1^G &= \frac{\bar{\pi}_1}{\hat{M}}, & \pi_2^G &= \frac{\bar{\pi}_2}{\hat{M}} M_1 \\ \pi_1^B &= \frac{\bar{\pi}_1}{\hat{M}}(1-M_2) & \pi_2^B &= \frac{\bar{\pi}_2}{\hat{M}} \end{aligned} \tag{1.17}$$

Crucially, the masses of green upstream and downstream firms, M_1 and M_2, affect some firm types' production and profits even when market integration $\hat{M}$ is considered fixed. We will distinguish between the following two effects.

Definition 1 (Green supply effect.) *The effect of marginally increasing M_1 on y_2^G and π_2^G while considering $\hat{M}$ fixed, $\partial \frac{y_2^G}{\partial M_1}\Big|_{\bar{\hat{M}}}, \partial \frac{\pi_2^G}{\partial M_1}\Big|_{\bar{\hat{M}}} > 0$.*

Definition 2 (Green demand effect.) *The effect of marginally increasing M_2 on y_1^B and π_1^B while considering $\hat{M}$ fixed, $\partial \frac{y_1^B}{\partial M_2}\Big|_{\bar{\hat{M}}}, \partial \frac{\pi_1^B}{\partial M_2}\Big|_{\bar{\hat{M}}} < 0$.*

Definition 3 (Integration effects.) *The effects of marginally increasing M_1 and M_2 on any firm types' production and profit that run through $\hat{M}$. For $k \in \{1, 2\}$, $n \in \{y, \pi\}$, $\frac{\partial n_k}{\partial \hat{M}} \frac{\partial \hat{M}}{\partial M_1} < 0$, $\frac{\partial n_k}{\partial \hat{M}} \frac{\partial \hat{M}}{\partial M_2} > 0$.*

The first arises because increasing the mass of green suppliers makes green downstream firms more productive. The second one derives from the lower demand for brown suppliers when more downstrean firms are green. The third arises as an aggregate effect from the change in the economy-wide production efficiency. Through these channels, the SRI may aim to affect production and share prices across markets when choosing the optimal intervention. Since the externality is a by-product of production, these effects are also reflected in total pollution. Defining the total externality arising from (M_1, M_2) as

$$\Phi(M_1, M_2) \equiv \phi_1 y_1^B (1 - M_1) + \phi_2 y_2^B (1 - M_2) \tag{1.18}$$

we can establish the following comparative statics result.[10]

Lemma 1 (Total externality.) *The total externality Φ is weakly decreasing in both M_1 and M_2. It is strictly decreasing in M_1 iff $M_2 < 1$ and strictly decreasing in M_2 iff $M_1 > 0$.*

The most obvious effect of bigger masses of green firms is that less firms produce the externality. However, this consideration only describes the extensive margin, i.e. the quantity effects when type-specific firm-level outputs are held constant. Besides the quantity effect, also the green demand effect occurs when M_2 is increased. Since brown inputs are demanded less, brown upstream pollution also decreases at the intensive margin.

However, note that the total externality is not diminished by higher M_2 when $M_1 = 0$, which is due to the countervailing integration effect and will become important later. Firstly, in this case, green downstream firms cannot produce because no green inputs are available to them. Therefore, there is no effect on upstream externality production: the integration effect fully cancels out the green demand effect.

At the same time, brown downstream firms can buy from all upstream firms. When additional firms turn green and therefore shut down their production, the unchanged available quantities of input varieties are instead demanded by the remaining brown firms. These firms scale up their production and therefore pollution. For the extreme case $M_1 = 0$, the reduction in pollution through fewer brown firms is exactly canceled out by the increase in the remaining brown firms' production: the integration effect fully cancels out the quantity effect. When $M_1 > 0$, downstream firms that turn green do produce (albeit inefficiently and therefore only relatively small amounts). Then, the increase in brown firms'

[10] All proofs can be found in Appendix 1.A.2.

capacity when M_2 increases does not fully match the decrease in green firms' production.[11]

1.5.2 Endogenous greening equilibria given (m_1, m_2).

We can now move on to the second step, in which we analyse the incentives that F-investors have to employ the green technology. For some given SRI policy (m_1, m_2), and in anticipation of the equilibrium allocation (1.17), one of three cases must apply in equilibrium:

$$\begin{array}{llll} I. & \pi_1^G - \kappa_1 < \pi_1^B & \text{and} & \tilde{m}_1 = 0 \\ II. & \pi_1^G - \kappa_1 = \pi_1^B & \text{and} & \tilde{m}_1 \in \left[0, 1 - m_1\right] \\ III. & \pi_1^G - \kappa_1 > \pi_1^B & \text{and} & \tilde{m}_1 = 1 - m_1 \end{array}$$

In the first case, all upstream F-investors strictly prefer to remain brown, so there is no endogenous greening. In the second case, F-investors are indifferent between turning green or not, and $\tilde{m}_1$ is pinned down by this indifference condition in equilibrium. In the last case, all remaining upstream firms are turned green since this yields a strictly higher net profit.

Which case arises in equilibrim depends on the SRI's choice. The following proposition specifies the equilibrium region as a function of (m_1, m_2).

Proposition 1 (Endogenous greening) *Let $D_1 \equiv \frac{\kappa_1}{\bar{\pi}_1}$. Then, given SRI policy (m_1, m_2),*

$$\tilde{m}_1(m_1, m_2) = \begin{cases} 0 & \textit{if } m_2 \le \bar{m}_2(m_1) \equiv \frac{D_1}{1+D_1(1-m_1)} & \textit{(region I)} \\ 1 - m_1 + \frac{1}{D_1} - \frac{1}{m_2} & \textit{if } m_2 \in (\bar{m}_2(m_1), D_1) & \textit{(region II)} \\ 1 - m_1 & \textit{else} & \textit{(region III)} \end{cases}$$

[11] A similar but (as we will see) less important effect arises when $M_2 = 1$: since no brown inputs are demanded, brown upstream firms do not produce and changes in M_1 do not affect the level of externality, which is zero.

Region I always exists, while region II exists iff $\frac{D_1}{1+D_1} < 1$*, and region III exists iff* $D_1 < 1$*. Under assumption **A2**,* $D_1 < 1$*, so all regions exist.*

This result is also shown graphically in Figure 1.3. When the investor purchases a low number of downstream firms, all of the unpurchased upstream firms remain brown. The reason is that the additional market profits from turning green are not sufficient to compensate F-investors for the fixed costs of greening.

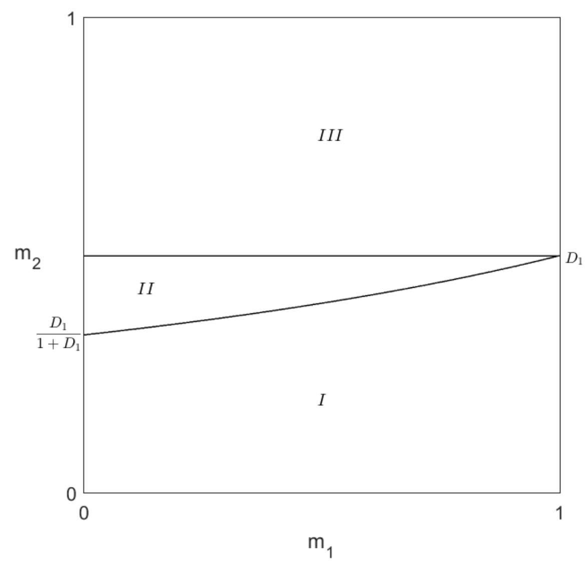


Figure 1.3: Endogenous greening regions.

For intermediate values of m_2, case II applies: a mass of upstream firms turns green endogenously, and in equilibrium upstream firms are indifferent between greening or not. The threshold that m_2 has to exceed is increasing in the mass of purchased upstream firms. The mechanism for this comes indirectly through market integration $\hat{M}$. When there are more suppliers that are controlled by the SRI, market integration is higher. Then, the aggregate consumption good is produced more efficiently, and firm-level profits are lower since the price level decreases. As a result, the additional market profits from greening become less relevant relative to the fixed greening costs, and more excess market profits are required to incentivize endogenous greening.

Finally, when m_2 is sufficiently high, all F-investors owning upstream firms are incentivized to turn their firms green, since the additional demand that they gain from this outweighs the monetary greening costs κ_1.

1.5.3 Investor choice.

Defining $E(m_1, m_2)$ as the total expenditure required to buy masses of firms (m_1, m_2),

$$E(m_1, m_2) = m_1 p_1^e + m_2 p_2^e \tag{1.19}$$

we now consider the full investor optimization problem. The SRI maximizes

$$\max_{m_1, m_2} \; W - E - \Phi$$

$$\begin{aligned} \text{s.t.} \quad & W - E \geq 0 && \textit{borrowing constraint} \\ & m_k \geq 0, 1 - m_k \geq 0, \;\; k = 1, 2 && \textit{non-negativity constraints} \end{aligned}$$

and additionally subject to the participation constraints (1.14), equilibrium production and profits (1.17), total externality (1.18), expenditure (1.19), and the endogenous greening response $\tilde{m}_1(m_1, m_2)$ from Proposition 1.

This problem can be solved by first solving for optimal region-specific policies, and then comparing the investor's utility across regions. It will be useful to establish another result, for which we denote with E_1, E_2 the derivatives of ependiture with respect to m_1 and m_2.

Lemma 2 (Total expenditure.) *Within region I, there exists a threshold $t_2(m_1) < \bar{m}_2$ s.t. $E_1 > 0$ if m_2 is below this threshold and $E_1 < 0$ if m_2 is above it. If $\kappa_2 < \bar{\pi}_1$, there exists a threshold $t_1(m_2) < 1$ s.t. $E_2 > 0$ if m_1 is below this threshold and $E_2 < 0$ if m_1 is above it. If $\kappa_2 > \bar{\pi}_1$, $E_2 > 0$. Within region II, $E_1 = 0$ and $E_2 < 0$. Within region III,*

$E_1 = 0$ and $E_2 > 0$.

First, consider region I, for which the result is shown graphically for the case $\kappa_2 < \bar{\pi}_1$ in Figure 1.4. Notably, increasing the amount of firms controlled by the SRI in sector 1 and sector 2 can lead to a decrease in expenditure. To understand this, first note that when either m_1 or m_2 is increased, the quantity effect of buying more firms at a given price leads to a higher expenditure.

On the other hand, there are also price effects. When m_1 is increased, the green supply effect arises. By broadening the set of available input varieties for green downstream firms, those firms obtain a higher profit. As a result, F-investors have to be compensated less, decreasing p_2^e and therefore expenditure. This effect dominates the quantity effect when m_2 is high, since then the investor benefits from the price effect for a higher mass of firms.

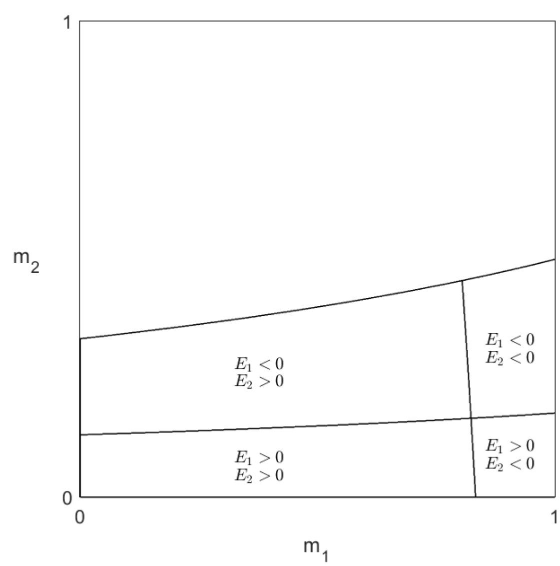


Figure 1.4: Response of expenditure to changes in m_1 and m_2 within region I when $\kappa_2 < \bar{\pi}_1$.

Similarly, when m_2 is raised, the green demand effect countervails the quantity effect. Increasing the demand for green suppliers' products boosts those firms' profits, and decreases their share price p_1^e. This effect is more pronounced when m_1 is higher, since then it applies to a larger mass of firms. However, unlike for E_1, it can occur that the price effect never dominates the quantity effect. That is the case when $\kappa_2 > \bar{\pi}_1$.

Note that changes in m_1 and m_2 additionally lead to changes in market integration $\hat{M}$, which also affects profits. However, these effects do note qualitatively change the results of Lemma 2, which is also shown in the proof.

In region II, $E_2 < 0$ signifies that the quantity effect is always dominated by what can be called the "endogenous greening effect". This channel is a chain reaction of green demand and green supply effect: the initial green demand effect from increasing m_2 leads to an increase in upstream firms that endogenously turn green, and therefore feeds back to downstream firms' profits through the green supply effect.[12]

The result for region III is straightforward. Suppliers' preference to turn green over remaining brown means that their share price is zero. For downstream firms, the share price is κ_2, because all upstream firms are green, so that all downstream firms have the same mass of suppliers and therefore equal profits. Thus, the only effect in this region is the quantity effect of increasing m_2, which always leads to higher expenditure.

Building on this result, we get the following characterization of optimal investor policy.

Proposition 2 (Optimal policy conditional on supply-chain policy.)
Define $\hat{W} \equiv D_1\kappa_2 = \frac{\kappa_2}{\bar{\pi}_1}$. Optimal SRI policy depends on wealth W as follows:

(i) *low wealth: there exists a $W_0 \in (0, \hat{W}]$ s.t. if $W < W_0$, there is no endogenous greening (region I) and optimal policies are $(m_1, m_2) = \left(\frac{W}{K_1}, 0\right)$*

(ii) *high wealth: if $W \geq \hat{W}$, there is full endogenous greening (region III), and so $\tilde{m}_1 = 1 - m_1$ and $M_1 = 1$, and optimal policy is $m_2 = \frac{W}{K_2} \geq D_1$*

(iii) *intermediate wealth: if $W \in [W_0, \hat{W})$, there is no endogenous greening (region I). As $W \to \hat{W}$ from below, the masses of green firms in equilibrium, M_1 and m_2, do not converge to $(1, D_1)$ if $\kappa_2 < \bar{\pi}_1$. They do converge if $\kappa_2 \geq \bar{\pi}_1$.*

Result (i) tells us that when W is sufficiently small, the SRI only buys upstream firms.

[12] Assumption A2 is sufficient but not necessary for the quantity effect to always be dominated in region II.

This holds even if $L = 2$, i.e. if $\frac{\kappa_2}{\phi_2} < \frac{\kappa_1}{\phi_1}$, and the intuition for it is twofold. To start with, when the investor budget is low, m_1 is necessarily small. Therefore, green downstream firms have few suppliers, so that their input price is high and their profits are low. As a result, compensating F-investors will be very costly. In the extreme, if $m_1 = 0$, green downstream firms cannot produce and their market profits are zero.

At the same time, when m_1 is low, the marginal environmental benefit of turning green more downstream firms is very small. This is because the remaining brown downstream firms increase their production in response, as explained in the context of Lemma 1 above. Thus, the total externality is only slightly diminished for low m_1, and the marginal benefit of increasing m_2 is low.

Result (ii) signifies that when W is sufficiently large, $W \geq \hat{W}$, the investor always buys a mass of downstream firms that is sufficient to induce all upstream firms to turn green. The intuition for this is that it allows her to turn all firms in the economy green, yet without having to pay the greening costs of upstream firms, as we will discuss in more detail further below. Region II never occurs in equilibrium, which follows directly from Lemma 1 and Lemma 2. Conditional on having enough funds, the SRI always prefers to trigger greening of all remaining suppliers, not just a subset.

The optimal investment choices for intermediate wealth depend on the parameters and are described in result (iii). Most notably, we find that if κ_2 is smaller than $\bar{\pi}_1$, the optimal policy for m_2 and the outcome for M_1 are discontinuous in W at $\hat{W}$. That is the amount of wealth at which the SRI has just enough funds to obtain control over the critical mass of downstream firms needed to switch from no endogenous greening in region I to full greening in region III. Therefore, to understand whether there is a jump in optimal choices, we need to understand whether the investor is choosing values for m_1 and m_2 that are bounded away from $(1, D_1)$ as W approaches $\hat{W}$ from below, i.e. in region I.

From Lemma 2, $\kappa_2 < \bar{\pi}_1$ implies that marginal increases in m_2 decrease expenditure for sufficiently high values of m_1. This is due to the green demand effect. At the same time, expenditure always decreases when m_1 is marginally increased at sufficiently high values of m_2, due to the green supply effect. Therefore, any choices in the upper right, upper left and lower right regions (see Figure 1.4) are strictly dominated by the corner solution $(1, D_1)$. Considering any of those dominated choices, the SRI will always prefer to buy $(1, D_1)$ because it causes a lower externality, while the additional purchases are at least least self-financing. This is because the green supply and green demand effects that this causes depress the outside option for the F-investors, so that the SRI has to pay less for these purchases.

However, for values $W < \hat{W}$, the investor is not wealth enough to trigger greening effects that are self-financing, and increasing purchases in any of the two sectors leads to higher expenses. Therefore, she can only afford a small portfolio of firms which is bounded away from $(1, D_1)$. The resulting policy function is plotted in the left panel of Figure 1.5.

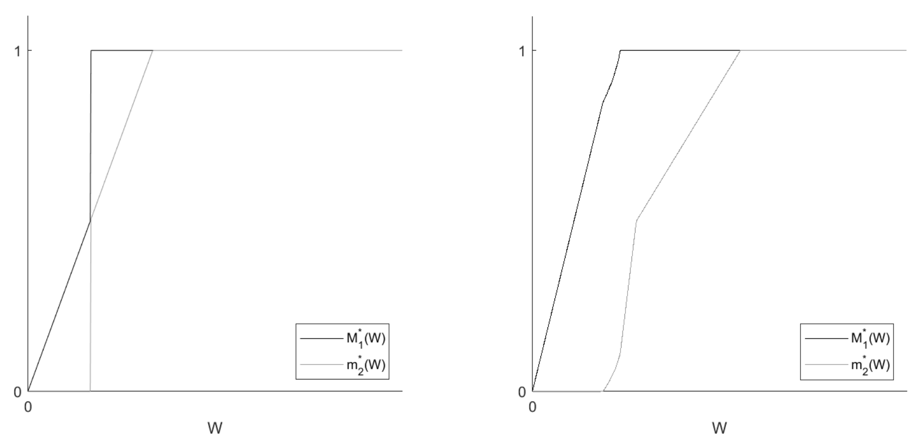


Figure 1.5: Optimal choices conditional on supply-chain enforcement for $\kappa_2 < \bar{\pi}_1$ (LHS) and $\kappa_2 > \bar{\pi}_1$

In the case that $\kappa_2 > \bar{\pi}_1$, the green demand effect never dominates the quantity effect, so increasing m_2 always increases expenses. As a result, the optimal policy is approaching $(1, D_1)$ continuously as W is approaching $\hat{W}$. This result is illustrated in the right panel of Figure 1.5.

1.5.4 Comparison of policies.

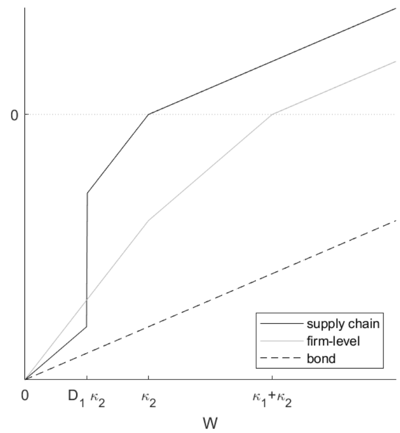
Does the investor always prefer to impose a green supply-chain rule? The answer to this question is no, and is formalized in the following result.

Proposition 3 (Optimal supply-chain policy.)
If $L = 1$: for
(i) $W < W_s$: the SRI is indifferent
(ii) $W \geq W_s$: strictly prefers supply-chain policy
where $W_s = W_0$.

If $L = 2$: for
(i) $W < W_s$: strictly prefers firm-level policy
(ii) $W \geq W_s$: strictly prefers supply-chain policy
where $W_s \geq W_0$.

The investor strictly prefers to not impose supply chain rules if $L = 2$ and W sufficiently low. But note that for W sufficiently large, she always strictly prefers to impose the supply chain policy, even when she is so wealthy that her borrowing constraint is slack. The reason is that employing the supply chain policy in her downstream firms makes sure that no externalities are emitted, but the greening cost of upstream firms are paid for by upstream F-investors themselves. Thus, the supply chain policy gives rise to a type of investment "multiplier": upon spending an amount of $\hat{W}$, additional monetary greening costs of κ_1 are paid for by F-investors.

Figure 1.6 illustrates the utility comparison for $L = 2$ in two different parameter regions of κ_2. In the left panel, $\kappa_2 < \bar{\pi}_1$, so there is an discontinuity in optimal policies and utiliy at $\hat{W} = D_1\kappa_2$. In the right panel however, $\kappa_2 > \bar{\pi}_1$, so there is no discontinuity.



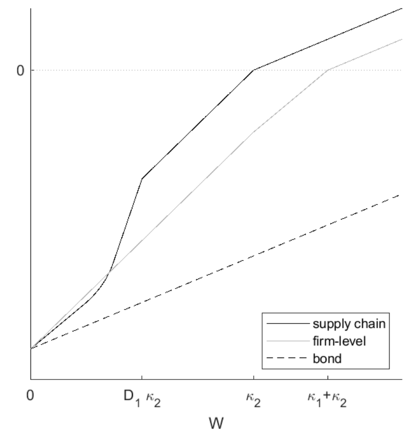


Figure 1.6: Investor utility under different policies when $L = 2$ for $\kappa_2 < \bar{\pi}_1$ (LHS) and $\kappa_2 > \bar{\pi}_1$ (RHS)

1.6 Conclusion

In this paper, I show that in the presence of a simple vertical production structure, the optimal intervention policy for a socially responsible investor depends on the relative size of her funds. When her capital is relatively scarce, imposing supply chain policies is not only expensive, but also ineffective. Therefore, it is optimal to target firms according to the relative costs of removing their firm level ("scope 1") emissions without imposing supply-chain policies.

Only when sufficient funds are available, it becomes affordable to buy a critical mass of downstream firms in order to incentivize upstream firms to turn green by means of a supply-chain requirement. In this case, impact becomes relatively cheap: there is an impact "multiplier" in the sense that the total greening cost in the economy is higher than the costs paid by the SRI, while the remaining amount is paid by financial investors. The finding of this paper demonstrates that it is crucial to consider spillover effects within and across markets, both for the non-financial impact of an investment as well as the financial cost of the investment portfolio.

In practice it may be difficult for socially responsible investors to take control of more upstream firms in the presence of global value chains. In that case, imposing supply-chain policies can can affect upstream externalities regardless, but they are more likely to be effective and cheap once a sufficiently big mass of downstream firms is implementing such a policy. This insight is also relevant for policy makers' design of supply chain regulations. In particular, if similar requirements are imposed on a larger number of more downstream firms internationally, more upstream firms are more prone to strategically transition to greener technologies.

1.A Appendix

1.A.1 Firm problems

Second stage downstream:

$$\max_{p_{2i}} \left[p_{2i} - P_1\right] y_{2i}(p_{2i})$$

$$\text{FOC: } y_{2i}(p_{2i}) + \left[p_{2i} - P_1\right] y_{2i}'(p_{2i}) = 0$$

$$y_{2i}'(p_{2i}) = -\epsilon \frac{y_{2i}}{p_{2i}}$$

Second stage upstream:

$$\max_{p_{1j}} \left[p_{1j} - w\right] y_{1j}(p_{1j})$$

$$\text{FOC: } y_{1j}(p_{1j}) + \left[p_{1j} - w\right] y_{1j}'(p_{1j}) = 0$$

$$y_{1j}'(p_{1j}) = -\epsilon \frac{y_{1j}}{p_{1j}}$$

1.A.2 Proofs

Proof of Lemma 1: Total externality. The total externality (1.18) is made up of sector-level externalities,

$$\Phi_{Sk}(M_1, M_2) \equiv \phi_k y_k^B (1 - M_k), \quad k = 1, 2$$

Compute

$$\begin{aligned}
\frac{\partial \Phi_{S1}}{\partial M_1} &= \phi_1\Big[-y_1^B + \frac{\partial y_1^B}{\partial M_1}(1-M_1)\Big] = -\phi_1\frac{1-M_2}{\hat{M}^2} && \leq 0\\
\frac{\partial \Phi_{S2}}{\partial M_1} &= \phi_2\frac{\partial y_2^B}{\partial M_1}(1-M_2) = -\phi_2\frac{M_2(1-M_2)}{\hat{M}^2} && \leq 0\\
\frac{\partial \Phi_{S1}}{\partial M_2} &= \phi_1\frac{\partial y_1^B}{\partial M_2}(1-M_1) = -\phi_1\frac{M_1(1-M_1)}{\hat{M}^2} && \leq 0\\
\frac{\partial \Phi_{S2}}{\partial M_2} &= \phi_2\Big[-y_2^B + \frac{\partial y_2^B}{\partial M_2}(1-M_2)\Big] = -\phi_2\frac{M_1}{\hat{M}^2} && \leq 0
\end{aligned}$$

so that

$$\Phi_1 \equiv \frac{\partial \Phi}{\partial M_1} = -\frac{1-M_2}{\hat{M}^2}[\phi_1 + M_2\phi_2] \quad \leq 0 \tag{1.20}$$

$$\Phi_2 \equiv \frac{\partial \Phi}{\partial M_2} = -\frac{M_1}{\hat{M}^2}[(1-M_1)\phi_1 + \phi_2] \leq 0 \tag{1.21}$$

where (1.20) holds with equality iff $M_2 = 1$ and (1.20) holds with equality iff $M_1 = 0$.

□

Proof of Proposition 1: Endogenous greening. In all cases, $M_2 = m_2$ since there is no endogenous downstream greening. For region I, suppose that $\pi_1^G - \kappa_1 < \pi_1^B$, so that $\tilde{m}_1 = 0$ and $M_1 = m_1$. Inserting the expressions for equilibrium profits from (1.17), this condition becomes

$$\frac{\bar{\pi}_1}{1-m_2(1-m_1)}m_2 < \kappa_1$$

and solving for m_2 yields

$$m_2 < \frac{\frac{\kappa_1}{\bar{\pi}_1}}{1+\frac{\kappa_1}{\bar{\pi}_1}(1-m_1)} \equiv \bar{m}_2(m_1)$$

For region II, suppose that $\pi_1^G - \kappa_1 = \pi_1^B$, so that $\tilde{m}_1$ is not yet pinned down. Again inserting equilibrium profits,

$$\frac{\bar{\pi}_1}{1-m_2(1-m_1-\tilde{m}_1)}m_2 = \kappa_1$$

This can be solved for

$$\tilde{m}_1(m_1, m_2) = 1 - m_1 + \frac{1}{D_1} - \frac{1}{m_2}$$

which is in the interval $(0, 1-m_1)$ for $m_2 \in (\bar{m}_2(m_1), D_1)$.

For region III, suppose that $\pi_1^G - \kappa_1 > \pi_1^B$, so that $\tilde{m}_1 = 1 - m_1, M_1 = 1$ and $\hat{M} = 1$.

Condition becomes

$$m_2 > D_1 \hat{M} = D_1$$

□

Proof of Lemma 2: Total expenditure.

Region I. In this region,

$$\begin{aligned} E(m_1, m_2) &= m_1 p_1^e + m_2 p_2^e \\ &= m_1 \left(\kappa_1 + \pi_1^B - \pi_1^G\right) + m_2 \left(\kappa_2 + \pi_2^B - \pi_2^G\right) \\ &= m_1 \left(\kappa_1 + \frac{\bar{\pi}_1}{\hat{M}}(1 - m_2) - \frac{\bar{\pi}_1}{\hat{M}}\right) + m_2 \left(\kappa_2 + \frac{\bar{\pi}_2}{\hat{M}} - \frac{\bar{\pi}_2}{\hat{M}} m_1\right) \\ &= m_1 \left(\kappa_1 - \frac{\bar{\pi}_1}{\hat{M}} m_2\right) + m_2 \left(\kappa_2 + \frac{\bar{\pi}_2}{\hat{M}}(1 - m_1)\right) \end{aligned} \tag{1.22}$$

First, show that $\exists\, t_2(m_1) \in (0, \bar{m}_2(m_1))$ s.t. $\frac{\partial E}{\partial m_1} \underset{(<)}{>} 0$ for $m_2 \underset{(>)}{<} t_2(m_1)$.

Compute

$$\begin{aligned} E_1(m_1, m_2) &= \kappa_1 - \bar{\pi}_1 \frac{m_2}{\hat{M}} && \text{quantity effect} \\ &- \bar{\pi}_2 \frac{m_2}{\hat{M}} && \text{green supply effect} \\ &+ \left[m_1 \frac{\partial p_1^e}{\partial \hat{M}} + m_2 \frac{\partial p_2^e}{\partial \hat{M}}\right] \frac{\partial \hat{M}}{\partial m_1} && \text{integration effect} \\ &= \kappa_1 - \frac{\bar{\pi}_1}{\hat{M}^2} m_2 (1 - m_2 + \mu) \end{aligned} \tag{1.23}$$

and evaluate this at end points, which gives

$$\begin{aligned} E_1(m_1, 0) &= \kappa_1 > 0 \\ E_1(m_1, \bar{m}_2) &= \kappa_1 \Big[1 - \underbrace{\Big(1 + D_1(1 - m_1)\Big)}_{\geq 1} \underbrace{(1 - m_2 + \mu)}_{>1}\Big] < 0 \end{aligned}$$

so by intermediate value theorem zeros exist. Further,

$$\frac{\partial E_1}{\partial m_2} = -\frac{\bar{\pi}_1}{\hat{M}^3} \Big[(1 + \mu)(1 - m_1 m_2) + m_2(\mu - 1)\Big] < 0 \tag{1.24}$$

so E_1 is monotonously decreasing in m_2 and there is a unique zero.

Note that this result does not qualitatively rely on the change in the integration effect. Considering only the quantity and green supply effect and denoting this adjusted derivative with $\tilde{E}_1$,

$$\tilde{E}_1(m_1, m_2) = \kappa_1 - \bar{\pi}_1(1+\mu)\frac{m_2}{\hat{M}}$$

for which it holds that $\frac{\partial \tilde{E}_1}{\partial m_2} < 0$ and

$$\begin{aligned}\tilde{E}_1(m_1, 0) &= \kappa_1 > 0 \\ \tilde{E}_1(m_1, \bar{m}_2(m_1)) &= -\bar{\pi}_1\mu < 0\end{aligned}$$

Moving on to response of E to changes in m_2, we now show that if $\kappa_2 > \bar{\pi}_1$, then $\exists\, t_1(m_2) \in (0,1)$ s.t. $\frac{\partial E}{\partial m_2} \underset{(<)}{>} 0$ for $m_1 \underset{(>)}{<} t_1(m_2)$, while if $\kappa_2 < \bar{\pi}_1$, get $\frac{\partial E}{\partial m_2} > 0\, \forall m_1$.

Compute

$$\begin{aligned}E_2(m_1, m_2) = \kappa_2 &+ \bar{\pi}_2\frac{1-m_1}{\hat{M}} && \text{quantity effect} \\ &- \bar{\pi}_1\frac{m_1}{\hat{M}} && \text{green demand effect} \\ &+ \left[m_1\frac{\partial p_1^e}{\partial \hat{M}} + m_2\frac{\partial p_2^e}{\partial \hat{M}}\right]\frac{\partial \hat{M}}{\partial m_2} && \text{integration effect} \\ &= \kappa_2 + \frac{\bar{\pi}_1}{\hat{M}^2}(\mu - m_1(\mu+1)) && \end{aligned} \tag{1.25}$$

which evaluated at end points gives

$$\begin{aligned}E_2(0, m_2) &= \kappa_2 + \frac{\bar{\pi}_1\mu}{(1-m_2)^2} > 0 \\ E_2(1, m_2) &= \kappa_2 - \bar{\pi}_1 \gtrless 0\end{aligned}$$

while

$$\frac{\partial E_2}{\partial m_1} = -\frac{\bar{\pi}_1}{\hat{M}^3}\Big[\underbrace{\mu}_{\geq 1}\underbrace{(1+m_2(1-m_1))}_{\in[1,2]} + \underbrace{1-m_2(1+m_1)}_{\in[-1,1]}\Big] < 0 \tag{1.26}$$

so E_2 is monotonously decreasing in m_1.

Note that again, the integration effect does not qualitatively affect this result:

$$\tilde{E}_2(m_1, m_2) = \kappa_2 + \frac{\bar{\pi}_1}{\hat{M}}[\mu(1-m_1) - m_1]$$

for which $\frac{\partial \tilde{E}_2}{\partial m_2} < 0$ and

$$\begin{aligned}\tilde{E}_2(0, m_2) &= \kappa_2 + \mu\frac{\bar{\pi}_1}{1-m_2} > 0 \\ \tilde{E}_2(0, m_2) &= E_2(1, m_2) = \kappa_2 - \bar{\pi}_1\end{aligned}$$

So the integration effect does not affect the condition for an interior threshold, $\kappa_2 < \bar{\pi}_1$. The reason for this is that when $m_1 = 1$, the integration effect is zero: changes in m_2 do not affect market integration, since all suppliers are green so that all downstream firms demand from all suppliers, irrespective of the mass of green downstream firms.

Region II. In this region, $p_1^e = 0$ since upstream F-investors are indifferent. Within this region, marginal changes in m_1 do not affect the allocation, since $\tilde{m}_1$ adjust and the total mass of green firms is a function only of m_2, $M_1(m_2) = 1 + \frac{1}{D_1} - \frac{1}{m_2}$.

$$E(m_2) = m_2 \left[\kappa_2 + \frac{\bar{\pi}_2}{\hat{M}}(1 - M_1(m_2)) \right]$$

Compute

$$\begin{aligned} E_2(m_2) = \kappa_2 + \bar{\pi}_2 \frac{1 - M_1}{\hat{M}} & \qquad \text{quantity effect} \\ - m_2 \frac{\bar{\pi}_2}{\hat{M}} \frac{\partial M_1}{\partial m_2} & \qquad \text{endogenous greening effect} \\ + m_2 \frac{\partial p_2^e}{\partial \hat{M}} \frac{\partial \hat{M}}{\partial m_2} & \qquad \text{integration effect} \\ = \kappa_2 - \frac{\bar{\pi}_2}{\hat{M}} \frac{1}{m_2} < 0 & \end{aligned}$$

where the inequality follows because $\hat{M} m_2 \leq 1$ and from Assumption 2.

Note that also this result is not qualitatively driven by the integration effect, since

$$\tilde{E}_2(m_2) = \kappa_2 - \frac{\bar{\pi}_2}{\hat{M}} \frac{1}{D_1} < 0$$

Region III. In this region, $p_1^e = 0$, $m_1 + \tilde{m}_1 = 1$, so $\hat{M} = 1$. $p_2^e = \kappa_2$, since profits are the same for green and brown downstream firms when all suppliers are green. So $E(m_2) = m_2 \kappa_2$ and $E_1 = 0$, while $E_2 = \kappa_2 > 0$.

□

Proof of Proposition 2: SRI choices. First, we derive optimal policy by region.

Region III. Within this region, $\tilde{m}_1 = 1 - m_1$, so $M_1 = 1$ and change in m_1 inconsequential. $p_2^e = \kappa_2$ since sector-2 profits coincide for B and G firms when all sector-1 firms are green. Thus, the minimum expenditure necessary to afford choices in this region is $\hat{W} \equiv D_1 \kappa_2$.

Under A1, marginal cost of increasing m_2, κ_2, is smaller than marginal benefit, ϕ_2. Then optimal policy, defined on $W \in [\hat{W}, \infty)$, is

$$m_2^{III}(W) = \begin{cases} \frac{W}{\kappa_2} & \text{if } W \in \left(\hat{W}, \kappa_2\right) \\ 1 & \text{else} \end{cases}$$

Region II. Using Lemma 1, the externality is strictly decreasing in m_2 in this region. At the same time, from Lemma 2, expenditure is decreasing in m_2. Therefore, the optimal region-specific choice is defined on $W \in [\hat{W}, \infty)$, and is equal to the maximum possible purchase in this region,

$$m_2^{II}(W) = D_1$$

Region I.

$E(0, 0) = 0$, and so a weak subset of choices in this region can be considered by the SRI at any $W \in [0, \infty)$.

First, establish that $m_1 > 0$ whenever $W > 0$. That is because $\Phi_2(0, m_2) = 0$ but $E(0, m_2) = \kappa_2 + \frac{\bar{\pi}_1 \mu}{(1-m_2)^2} > 0$, i.e. the marginal benefit of increasing m_2 is always zero when $m_1 = 0$, but the marginal cost is strictly positive.

Second, note that by Lemma 1, the corner $(1, D_1)$ is the choice with the lowest externality in region I. It requires an expenditure of

$$E(1, D_1) = p_1^e + D_1 p_2^e = 0 + D_1 \kappa_2 = \hat{W}$$

where $p_1^e(1, D_1) = 0$ intuitive since $(1, D_1)$ lies on the boundary to region II, in which sector-1 F-investors are indifferent. So for $W \geq \hat{W}$, the optimal choice within region I is always $(1, D_1)$. For $W < \hat{W}$, the optimal region I choices will be the optimal overall choices, since regions II and III require $W \geq \hat{W}$, as we saw above.

Defining the objective as $\tilde{f} = W - E - \Phi$, Kuhn-Tucker equations are

$$\begin{aligned} -(1+\gamma)E_1 - \Phi_1 - \eta_1^H + \delta \bar{m}_2 (m_1)^2 &= 0 \\ -(1+\gamma)E_2 - \Phi_2 + \eta_2^L - \delta &= 0 \\ \gamma\,(W - E) &= 0 \\ \eta_1^H (1 - m_1) &= 0 \\ \eta_2^L m_2 &= 0 \\ \delta(\bar{m}_2 - m_2) &= 0 \end{aligned}$$

However, this maximization problem is not "well behaved", since $\tilde{f}$ is not quasi-concave over the whole domain of region I. To solve this problem, we will first restrict the choice set by exluding strictly dominated options.

Consider first the case $\kappa_2 < \bar{\pi}_1$.

1. Exclude dominated regions. From Lemma 2, all four subregions for the behaviour

of expenditure exist. In the upper right subregion (see Figure 1.4), all choices will be strictly dominated by the corner $(1, D_1)$ in that it does not only lead to a lower externality, but is also cheaper. The same holds for all choices in the upper left and lower right subregion.

So for $W < \hat{W}$, we need to search withing the lower left subregion, call it R.

2. Constraints in R. m_2 is strictly below the boundary for region I, i.e. the constraint $\bar{m}_2(m_1) - m_2 \geq 0$ is slack, and so $\delta = 0$. Also, $m_1 < 1$ in R, so $\eta_1^H = 0$. Argue that borrowing constraint is always binding in R, i.e. $\gamma > 0$: could always buy more m_1 which increases E in R, but is preferred. Under A1, it is preferred over investing into the bond in the firm-level greening case, where the share price is κ_1 and p_2^e is fixed. Since $\pi_1^B \leq \pi_1^G$, p_1^e is now weakly lower than κ_1, which can also be seen in expression (1.22). Also, increasing m_1 decreases p_2^e through both the green supply and integration effect.

3. Redefine objective. Since $W - E = 0$ is always optimal, can redefine objective as $f = -\Phi$, which will be maximized subject to the remaining set of equality and inequality constraints and the system of Kuhn-Tucker equations boils down to

$$-\gamma E_1 - \Phi_1 = 0 \tag{1.27}$$
$$-\gamma E_2 - \Phi_2 + \eta_2^L = 0 \tag{1.28}$$
$$W - E = 0 \tag{1.29}$$
$$\eta_2^L m_2 \geq 0 \tag{1.30}$$

where E, E_1, E_2, Φ_1 and Φ_2 are spelled out in (1.20)-(1.25).

$g_2 \equiv m_2$ is linear and therefore quasi-concave. Can show that $g_1 \equiv W - E$ is quasiconcave for $W \leq \hat{W}$ by computing bordered Hessian and checking that its determinant is strictly positive. With $-E$ quasi-concave, we obtain convex lower contour sets for expenditure. Can show that f is quasiconcave, so that lower contour sets for the externality are convex. Then the solution of this maximization problem is unique, and necessity and sufficiency of the Kuhn-Tucker conditions hold for $W < \hat{W}$.

Therefore, two possibilities remain. Either there is an interior solution, $\eta_2^L = 0$, at which the expenditure isoline (budget set) and the externality isoline touch, with slopes $-\frac{\Phi_1}{\Phi_2} = -\frac{E_1}{E_2}$. Or there is a corner solution $m_2 = 0$, and in that point the externality isoline has a steeper slope that the budget set,

$$-\frac{\Phi_1}{\Phi_2} = -\frac{E_1}{E_2} + \underbrace{\frac{\eta_2^L}{\Phi_2}\frac{E_1}{E_2}}_{<0}$$

4. Solve. Suppose $\eta_2^L > 0$, so $m_2 = 0$ and from binding borrowing constraint (1.29), $m_1 = \frac{W}{\kappa_1} < \frac{\kappa_2}{\bar{\pi}_1} < 1$. Under $m_2 = 0$, $E_1 = \kappa_1$, $\Phi_1 = \phi_1$, so from (1.27), $\gamma = \frac{\phi_1}{\kappa_1}$. Inserting into (1.28) while using $E_2 = \kappa_2 + \bar{\pi}_1[\mu - m_1(\mu + 1)]$ and $\Phi_2 = -m_1[(1 - m_1)\phi_1 + \phi_2]$

gives

$$h(W) \equiv \eta_2^L = \frac{\phi_1}{\kappa_1}\Big[\kappa_2 + \bar{\pi}_1(\mu - \frac{W}{\kappa_1}(\mu+1))\Big] - \frac{W}{\kappa_1}\Big[\phi_1(1-\frac{W}{\kappa_1}) + \phi_2\Big]$$

Examining the end points,

$$\begin{aligned} h(0) &= \frac{\phi_1}{\kappa_1}\Big[\kappa_2 + \bar{\pi}_1\mu\Big] > 0 \\ h(\hat{W}) &= \frac{1}{\bar{\pi}_1}\Big[\underbrace{(\bar{\pi}_1 - \kappa_2)}_{>0}\frac{\phi_1}{\kappa_1}\underbrace{(\mu\bar{\pi}_1 - \frac{\kappa_1\kappa_2}{\bar{\pi}_1})}_{>0} - \kappa_2\phi_2\Big] \\ &\underset{(<)}{>} 0 \text{ iff } \kappa_2 \underset{(>)}{<} \beta\bar{\pi}_1 \end{aligned}$$

with

$$\beta = \frac{1}{2}\left[z + \frac{\phi_1+\phi_2}{\phi_1} - \sqrt{\left[z + \frac{\phi_1+\phi_2}{\phi_1}\right]^2 - 4z}\right] \in (0,1)$$

where $z \equiv \frac{\bar{\pi}_1\mu}{\kappa_1}$ and the discriminant can be shown to be strictly positive. Now it remains to check the derivative,

$$\begin{aligned} h'(W) &= \frac{1}{\kappa_1^2}\Big[W2\phi_1 - \phi_1\bar{\pi}_1(\mu+1) - \kappa_1(\phi_1+\phi_2)\Big] \\ &\underset{(<)}{>} 0 \text{ iff } W \underset{(<)}{>} \kappa_1\frac{\phi_1+\phi_2}{2\phi_1} + \bar{\pi}_1\frac{\mu+1}{2} > \kappa_1 \end{aligned}$$

where the last inequality follows from A2 and $\mu + 1 \geq 2$. Since we are considering $W < \hat{W} = D_1\kappa_2 = \kappa_1\frac{\kappa_2}{\bar{\pi}_1} < \kappa_1$, we get that $h(W)$ is monotonously decreasing in W in the relevant parameter space.

In the following, define W_0 as the highest W at which $m_2(W) = 0$. Summing up, if $\kappa_2 \leq \beta\bar{\pi}_2$, $m_2(W) = 0$ for $W \in [0, \hat{W})$, and $W_0 = \hat{W}$. If $\kappa_2 \in (\beta\bar{\pi}_1, \bar{\pi}_1)$, there exists a threshold value $\underline{W} < \hat{W}$ s.t. $m_2(W) = 0$ when $W \leq \underline{W}$, but $m_2(W)$ interior when $W \in (\underline{W}, \hat{W})$. Therefore, $W_0 = \underline{W}$.

Since $h(W)$ is quadratic in W, can solve analytically for

$$\underline{W} = \frac{1}{2}\left[\bar{\pi}_1(\mu+1) + \kappa_1\frac{\phi_1+\phi_2}{\phi_1} - \sqrt{\left[\bar{\pi}_1(\mu+1) + \kappa_1\frac{\phi_1+\phi_2}{\phi_1}\right]^2 - 4[\kappa_1\kappa_2 + \bar{\pi}_1\mu]}\right]$$

Now, consider case $\kappa_2 > \bar{\pi}$.

1. Regions. From Lemma 2, only the two left regions for the behaviour of expenditure exist. We again refer to the lower region as R. Note that the upper region corner choices, $(1, m_2)$ for $m_2 \geq t_2(1)$, dominate all the other choices in the upper region: in-

creasing m_1 while holding m_2 constant decreases both the externality and expenditure. Also, the cheapest choice in the upper region, $(1, t_2(1))$, yields a lower externality than any of the choices in R. So whenever this choice is affordable, it will be preferred over all of the choices in R.

Using (1.23), $t_2(m_1)$ is defined implicitly by $E_1(m_1, t_2(m_1)) = 0$, so that $t_2(1)$ can be calculated to be

$$t_2(1) = \frac{1}{2}\left[1 + \mu - \sqrt{(1+\mu)^2 - 4\frac{\kappa_1}{\bar{\pi}_1}}\right]$$

and expenses are

$$E(1, t_2(1)) = \kappa_1 + t_2(1)[\kappa_2 - \bar{\pi}_1] > E(1, 0) = \kappa_1$$

Therefore, for $W \geq E\left(1, t_2(1)\right)$, $m_1(W) = 1$. The optimal choice of m_2 is implicitly defined by $E(1, m_2(W)) = W$, and yields $m_2(W) = \frac{W-\kappa_1}{\kappa_2-\bar{\pi}_1}$.

2. Constraints in R. As for case $\kappa_2 < \bar{\pi}$ above, except that may now get $\eta_1^H > 0$ and $m_1 = 1$.

3. Redefine objective. As for case $\kappa_2 < \bar{\pi}$ above, but now need to accomodate for the possibility that $m_1 = 1$. Borrowing constraint always binding even when $m_1 = 1$: always prefer to increase m_2, since when $m_1 = 1$, $-E_2 - \Phi_2 = -(\kappa_2 - \bar{\pi}_1) + \phi_2 > 0$ under A1.

   System of equations

$$-\gamma E_1 - \Phi_1 - \eta_1^H = 0 \tag{1.31}$$
$$-\gamma E_2 - \Phi_2 + \eta_2^L = 0 \tag{1.32}$$
$$W - E = 0 \tag{1.33}$$
$$\eta_2^L m_2 \geq 0 \tag{1.34}$$
$$\eta_1^H (1 - m_1) \geq 0 \tag{1.35}$$

4. Solve. Suppose $\eta_2^L > 0 \Rightarrow m_2 = 0$. Consider $W \leq \kappa_1$, which is expenditure that would be required to purchase $(1, 0)$, and therefore $\eta_1^H = 0$ (since $m_1 > 1$ are ruled out by borrowing constraint). Then $h(W)$ same as for $\kappa_2 < \bar{\pi}_1$. Now the relevant end point is

$$\begin{aligned} h(\kappa_1) &= \frac{\phi_1}{\kappa_1}[\kappa_2 - \bar{\pi}_1] - \phi_2 \\ &\underset{(<)}{\geq} 0 \text{ iff } \kappa_2 \underset{(<)}{\geq} \bar{\pi}_1 + \frac{\phi_2}{\phi_1}\kappa_1 \end{aligned}$$

Therefore, when $\kappa_2 \geq \bar{\pi}_1 + \frac{\phi_2}{\phi_1}\kappa_1$, get

$$m_1^I(W) = \begin{cases} \frac{W}{\kappa_1} & \text{if } W \leq \kappa_1 \\ 1 & \text{else} \end{cases}$$

$$m_2^I(W) = \begin{cases} 0 & \text{if } W \leq \kappa_1 \\ \frac{W-\kappa_1}{\kappa_2-\bar{\pi}_1} & \text{if } W \in (\kappa_1, \hat{W}) \\ D_1 & \text{else} \end{cases}$$

and $W_0 = \kappa_1$. For $\kappa_2 < \bar{\pi}_1 + \frac{\phi_2}{\phi_1}\kappa_1$, $\exists \underline{W}$ s.t. get interior solutions for $W \in (\underline{W}, E(1, t_2(1))]$, and $W_0 = \underline{W} < \kappa_1$.

The corresponding parameter regions are displayed in Figure 1.7. The upper boundary $\min\{\phi_2, \mu\bar{\pi}_1\}$ comes from A1 and A2. Given a set of parameters exluding κ_2, region (a) always exists, while the other regions may not exist. □

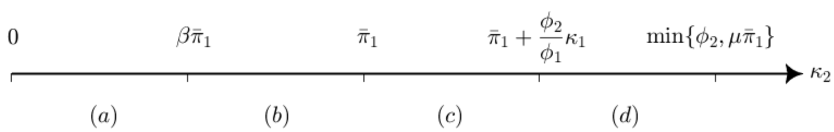


Figure 1.7: Parameter regions for intermediate $W \in [W_0, \hat{W})$

Proof of Proposition 3: Policy preference. Under firm-level policy, investor utility is

$$u^F(W) = \begin{cases} -[(1-\frac{W}{\kappa_L})\phi_L + \phi_H] & \text{if } W \leq \kappa_L \\ -(1-\frac{W-\kappa_L}{\kappa_H})\phi_H & \text{if } W \in (\kappa_L, \kappa_L+\kappa_H) \\ W - (\kappa_1+\kappa_2) & \text{else} \end{cases}$$

For supply-chain policy, note that $\hat{W} = D_1\kappa_2 = \kappa_1\frac{\kappa_2}{\bar{\pi}_1}$ is the same across regions, while W_0 will be region-specific and denotes the lowest W at which $m_2 > 0$. Investor utility under supply-chain policy is

region (a)

$$u^S(W) = \begin{cases} -[(1-\frac{W}{\kappa_1})\phi_1 + \phi_2] & \text{if } W < W_0 \\ -(1-\frac{W}{\kappa_2})\phi_2 & \text{if } W \in [W_0, \kappa_2] \\ W - \kappa_2 & \text{else} \end{cases}$$

region (b)

$$u^S(W) = \begin{cases} -[(1-\frac{W}{\kappa_1})\phi_1 + \phi_2] & \text{if } W \leq W_0 \\ u^S_{int}(W) & \text{if } W \in (W_0, \hat{W}) \\ -(1-\frac{W}{\kappa_2})\phi_2 & \text{if } W \in [\hat{W}, \kappa_2] \\ W - \kappa_2 & \text{else} \end{cases}$$

where we are not solving explicitly for W_0 and $u^S_{int}(W)$, but know that $u^S_{int}(W) \in \Big(-[(1-\frac{W}{\kappa_1})\phi_1 + \phi_2], -(1-\frac{W}{\kappa_2})\phi_2\Big)$.

region (c) and (d)

$$u^S(W) = \begin{cases} -[(1-\frac{W}{\kappa_1})\phi_1 + \phi_2] & \text{if } W \leq W_0 \\ u^S_{int}(W) & \text{if } W \in (W_0, \hat{W}) \\ -(1-\frac{W}{\kappa_2})\phi_2 & \text{if } W \in [\hat{W}, \kappa_2] \\ W - \kappa_2 & \text{else} \end{cases}$$

where we are not solving explicitly for W_0 and $u^S_{int}(W)$, but know that $u^S_{int}(W) \in \Big(-[(1-\frac{W}{\kappa_1})\phi_1 + \phi_2], -(1-\frac{W}{\kappa_2})\phi_2\Big)$.

Denote with $\Delta = \Delta(W) \equiv u^s(W) - u^F(W)$. Let $l \in \{1,2\}$ be the sector with the lower κ_k, and h be the other sector.

First consider case $L = 1$. In all regions, for $W < W_0$, both strategies yield same utility and the investor is indifferent since only buy upstream. Also, the following holds in all regions regions: for $W \in [\hat{W}, \kappa_l]$, $\Delta = (1-\frac{\kappa_2}{\bar{\pi}_1})\phi_1 + \frac{\kappa_1}{\bar{\pi}_1}\phi_1 > 0$. For $W \in (\kappa_l, \kappa_h]$, $\Delta = \frac{\kappa_1}{\kappa_2}\phi_2 > 0$. For $W \in (\kappa_h, \kappa_1+\kappa_2)$, $\Delta = -W(\frac{\phi_2}{\kappa_2} - 1) - \kappa_2 + \phi_2(1+\frac{\kappa_1}{\kappa_2}) \geq \kappa_1 > 0$. For $W \geq \kappa_1 + \kappa_2$, $\Delta = \kappa_1 > 0$.

Parameter region (a). From Proposition 2, $W_0 = \hat{W}$ in this region, so $W_s = W_0 = \hat{W}$.

Parameter region (b) and (c). In these regions, as in (d), have $W_0 < \hat{W}$. In interval $W \in [W_0, \hat{W})$, "revealed preference" type argument: must have $u^S > u^F$, since the same allocation as under firm-level policy is available under supply-chain policy. Therefore, $W_s = W_0$.

Parameter region (d). From Proposition 2, $W_0 = \kappa_1$ in this region, i.e. first buy all the upstream firms even under supply chain policy. For $W_0 \in [\kappa_1, \kappa_2]$, start additionally buying downstream firms, which is cheaper under supply-chain policy. As a result, $\Delta = \frac{\kappa_1}{\kappa_2}\phi_2 > 0$. So $W_s = W_0 = \kappa_1$.

Now consider case $L = 2$. In this case, region (d) never exists. In all existing regions, for $W < W_0$, $\Delta = W(\frac{\phi_1}{\kappa_1} - \frac{\phi_2}{\kappa_2}) < 0$, so strictly prefers firm-level policy. Also, for $W \in [\hat{W}, \kappa_2]$, $\Delta = \phi_1 > 0$. For $W \in (\kappa_2, \kappa_1+\kappa_2)$, $\Delta = \kappa_1 > 0$. For $W \geq \kappa_1+\kappa_2)$, $\Delta = \kappa_1 > 0$.

Parameter region (a). In this region, $W_0 = \hat{W}$, so $W_s = W_0 = \hat{W}$.

Parameter region (b). For $W = W_0$, $\Delta = W_0(\frac{\phi_1}{\kappa_1} - \frac{\phi_2}{\kappa_2}) < 0$.

Parameter region (c). For $W \to \hat{W}$ from below, $u^S(W) \to u^S(\hat{W})$, i.e no jump in utility in this region. Thus, W_s strictly below $\hat{W}$ and $W_s \in (W_0, \hat{W})$.

□

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Chapter 2: Flow Costs of Equity and the Dynamic Effects of Capital Requirements

2.1 Introduction

The optimal level of bank capital requirements (CR) is determined by the tradeoff of the benefits and costs of this regulatory tool. So-called long-term economic impact models (e.g. BCBS (2010), surveyed by Birn et al. (2020)) have been quantifying the benefits in the form of lower crisis probabilities and lower conditional crisis costs as well as its potential costs resulting from lower levels of lending. However, there is notable disagreement, not only between practitioners and academics but also within the academic debate, about the optimal level of CR (e.g. Admati et al. (2013), Aiyar et al. (2015)). In a survey of banking scholars, Ambrocio et al. (2020) document that the driving factor behind researchers' diverging preferences for the level of CR is their belief of how they affect costs, rather than benefits.

The costliness of tightened CR in terms of reduced lending activity is determined by the extent to which they generate an increase in funding costs. A measure for this is the so-called Modigliani-Miller offset (e.g. Birn et al. (2020)), in reference to the capital structure indeterminacy result by Modigliani and Miller (1958). In the case of a full offset, the increased costs for equity provision are entirely offset by the decrease in interest rates stemming from lower leverage and therefore lower default risk.[1] However, frictions drive a wedge between the funding costs of debt and equity, leading to incomplete offsets.

[1]Recent evidence supports that investors correctly adjust return expectations to changes in risk in this context (Dick-Nielsen et al. 2022).

These frictions have been widely analyzed in tradeoff theories of the capital structure and determine the long-run response of lending to capital regulation.

The disagreement observed by Ambrocio et al. (2020) may be due to differing estimates of long-term costs, as summarized by Birn et al. (2020). However, the motivation for my paper builds on the premise that another factor contributing to the disagreement could be a lack of differentiation between transitory and long-run costs in the empirical and theoretical literature. Temporary costs derive from a different set of frictions that break the Miller and Modigliani (1961) benchmark result of equivalence of external and internal equity financing. Introducing an intertemporal dimension to the equity financing decision, these frictions may lead to a gradual buildup of equity through retained earnings and to the non-monotonous lending response to CR tightenings that is found by empirical studies (e.g. Eickmeier et al. (2018)). Macroeconomic banking models calibrated to match these patterns suggest that the transitory costs of changes in CR may offset 25% of long-run welfare gains (Mendicino et al. (2020)). And given this sizeability, a lack of clear distinction between short and long run costs of equity is likely to lead to calls for levels of CR that are suboptimally low.

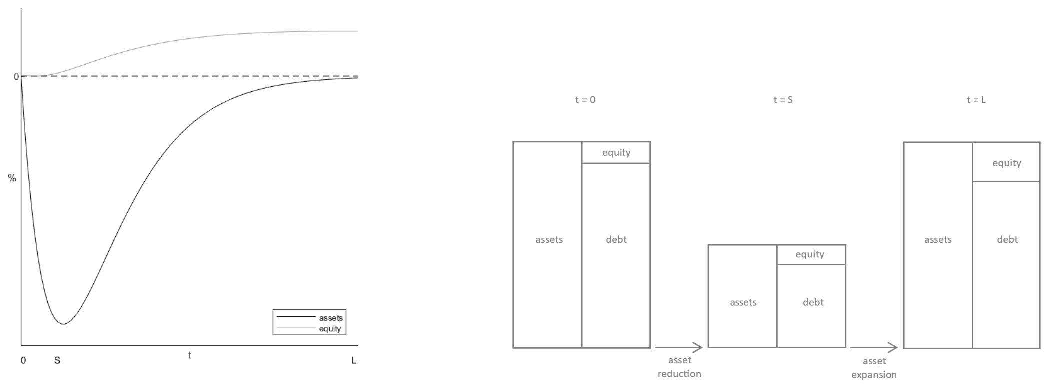
Frictions leading to flow costs of equity (Greenwood et al. (2017)) have not been systematically considered jointly in the dynamic capital structure literature. This paper aims to fill this gap by giving an overview over the following mechanisms and their interactions: direct issuance costs, asymmetric information, debt overhang, control dilution reluctance and inelastic equity supply. The collected empirical and theoretical literature suggests that these frictions are jointly important, but banking-specific empirical results that support the single channels are sparse for most of them. Policy implications for bank regulation depend on the contribution of the single frictions to the total flow cost of equity.

This paper proceeds as follows. In section 2.2, I motivate the research questions by discussing empirical evidence of banks' short and long run balance sheet reactions to changes in capital regulation. Section 2.3 provides an overview over five distinct frictions that rationalize the observed patterns in equity issuance and lending. I go through the frictions one-by-one, discussing their theoretical underpinnings and empirical merits for the banking sector. In section 2.4, the frictions are considered jointly allowing to uncover possible interactions between them. Based on this, I derive policy implications in 2.5 before concluding in section 2.6.

2.2 Empirical evidence

Mechanically, how may banks go about meeting a higher level of capital ratio? As illustrated by Admati et al. (2018), banks can choose between three alternative strategies to reduce their leverage: asset sales, pure recapitalizations, or asset expansions. Asset sales allow to buy back debt, so that the equity-to-asset ratio can be reduced without increasing the absolute level of equity. Instead, pure recapitalizations rest on an increase in the level of equity replacing debt funding, while the size of the balance sheet is kept constant. Finally, in the case of asset expansions, new equity funding is used to acquire more assets. While debt is kept constant, the level of equity is increased, allowing to meet a higher level of capital requirements.

Lending and capital responses. Eickmeier et al. (2018) provide evidence on the dynamic effects of capital requirements on aggregate bank lending. They cover US banks from 1979 to 2016, identifying arguably exogenous tightenings in capital requirements based on a narrative approach. This allows them to employ the local projection method to estimate impulse response functions to these changes. The authors find that banks initially reduce their assets, while equity is increased only gradually and after a delay. They find that these adaptations last approximately two years. Thus, their results suggest the shape of aggregate balance sheet responses as illustrated in the left panel of Figure 2.1. In the short run ($t = S$), banks cut back lending, avoiding to increase their capital ratios. In the long run ($t = L$), equity levels increase and lending recovers. In terms of the balance sheet mechanics discussed above, this maps into a short-run asset reduction and a subsequent asset expansion, as illustrated in the right panel of Figure 2.1.



(a) Impulse responses. (b) Balance sheet adjustments.

Figure 2.1: Stylized responses of banks' balance sheets to a tightening in capital requirements.

While the study by Eickmeier et al. (2018) estimates the response of aggregate data, their finding is supported qualitatively by the meta-analysis of empirical estimates by Boissay et al. (2019). I discuss their findings and those of related meta-analyses in Appendix 2.A.1, while general equilibrium effects are discussed in Appendix 2.A.2. Regarding the long-run response of lending, the case depicted in Figure 2.1 exhibits a response of zero, i.e. there is a full Modigliani-Miller offset. While the transitory cutback in lending and sluggish equity buildup appear qualitatively robust findings in the literature, the sign of the long-run response of lending is contested, as discussed by Birn et al. (2020).

Equity issuance. Other empirical evidence adds a puzzle piece to this picture by analyzing the effect of capital regulation on banks' incentive to issue outside equity. In a cross-country study of banks, Dinger and Vallascas (2016) find that changes in capital regulation do not increase the likelihood of secondary equity issuances (SEOs) by poorly capitalized banks. This complements the story told by Figure 2.1, since it implies that banks avoid pure recapitalizations to meet more stringent capital regulation, leaving them with the options of asset shrinkages in the short run and retained earnings in the long run. Consistent with this, the results by Khan and Vyas (2015) suggest that the majority of losses incurred by banks during the financial crisis were not replenished through SEOs, but that banks resorted to other channels to restore their capital ratios.

Based on this evidence, the motivation for this paper is to assemble mechanisms that are jointly or separately able to rationalize them. We will consider their theoretical underpinnings as well as the empirical evidence for their plausibility in the banking sector.

2.3 Flow costs of equity

Capital structure theory. Static capital structure theory yields predictions about firms' capital structure by examining frictions that break the Modigliani-Miller theorem (Modigliani and Miller (1958)), pinning down optimal choices of debt and equity. These frictions, like tax subsidies for debt (making debt cheap) and default costs (making debt costly) are likely to contribute to the long-run effects of bank capital requirements: if lending in the new steady state is lower under tighter CR, this should be due to higher equity funding costs for banks. In contrast, the pecking order theory, which will become relevant in subsection 2.3.2, also yields predictions about the differential costs of issuing equity and retaining earnings.

My paper aims to contribute to the dynamic strand of capital structure theory.[2] This theory analyzes how shareholder-creditor conflicts affect decisions on both sides of the balance sheet in a dynamic setting. However, as pointed out by Admati et al. (2018), contributions to the literature are largely concerned with the dynamics of default and investment decisions while keeping the capital structure fixed. Dynamics of capital structure decisions through equity issuances are not yet in the focus of this literature and even changes in leverage are

[2] For reviews of dynamic capital structure theory, see Strebulaev and Whited (2012) and more recently Ai et al. (2020)

often restricted exogenously (e.g. Bhamra et al. (2010)). Some recent advances on dynamic evolutions in leverage become relevant in subsection 2.3.3 below.

Condensed from a variety of corporate finance and corporate governance literatures, I have collected five frictions that may make equity issuance more costly than building up equity through retained earnings: direct issuance costs, adverse selection, debt overhang, control dilution and inelastic equity supply. These may separately or jointly rationalize the empirical findings on the transition dynamics discussed above.[3] A summary of the bank-specific empirical evidence for each mechanism is eventually displayed in Table 2.1.

Objective function. As we will see, the prevalence of some of these frictions depends on the objective function of the bank. Given separation of ownership and control (Fama and Jensen (1983)), we are considering the bank manager's objective.[4] For each mechanism, we will specifiy the relevant assumption regarding the bank's objective and we will discuss their implications in more detail as they apply.

ASSUMPTION 1 *The bank manager maximizes the share value of current shareholders.*

The specification of current in contrast to future shareholders becomes important in the dynamic setting that we are discussing here, especially the cases of asymmetric information and dilution reluctance.

Additionally, note that shareholder value maximization is distinct from firm value maximization in the debt overhang scenario. This case gives rise to an agency issue between current shareholders and debtholders.

ASSUMPTION 2 *In deviation from Assumption 1, there are agency issues between the manager and the shareholders.*

[3]These issuance costs can also influence firm dynamics in the steady state. See e.g. Cooley and Quadrini (2001) for a model with equity issuance costs.

[4]We do not consider the possibility that capital structure decisions are influenced by imperfect knowledge of managers, as discussed by DeAngelo (2022).

As we will discuss, principal-agent conflicts (Jensen and Meckling (1976), Jensen (1986)) may interact with the frictions discussed here, impacting the balance sheet adjustments of banks.

ASSUMPTION 3 *In deviation from Assumption 1, there are agency conflicts between majority and minority shareholders.*

Note that in the presence of heterogeneous shareholders, the assumption of shareholder value maximization, Assumption 1, is not well defined. This opens up both empirical and theoretical research questions about the positive and normative objective function of firms, addressed for instance in the literature on common ownership of firms, in which heterogeneity arises through owners' diverging portfolios of firm shares (e.g. Azar and Vives (2021)).[5] In this literature, the manager is often merged into a black box of functions mapping ownership of control shares into weights in the objective function.[6]

For our purposes, there is no need to specify how exactly ownership of (control) shares translates into actual control weights in the objective of those managing the bank. We are merely positing that for a given ownership structure, the preferences of majority shareholders deviate from those of minority shareholders, so that "principal-principal" conflicts (Dharwadkar et al. (2000)) arise and actions may benefit the former while hurting the latter. Decisions regarding capital structure and lending decisions may be affected by this as well, as the case of dilution reluctance will show.

[5]While heterogenous preferences about competitive behaviour and risk taking are sufficient to open up the question about the firms' objective function, the presence of production externalities internalized by "socially responsible investors" (e.g. Hart and Zingales (2017)) complicates matters further. Normative academic and public debates about the "purpose" of the firm (e.g. Magill et al. (2015), Mayer (2018)) go even further by considering the maximization of stakeholder value.

[6]e.g. based on an assumption of proportional control (e.g. Azar and Vives (2021)) or Banzhaf weights (Banzhaf (1964)).

2.3.1 Direct issuance costs

Mechanism. Transaction costs arising from equity issuances are frequently evoked as a reason for banks' unwillingness to raise equity (e.g. Bolton and Freixas (2006), Dagher et al. (2020), Braouezec and Kiani (2021)). The mechanism through which this friction may lead to temporary, rather than permanent, effects of CR tightenings is straightforward: while issuance of outside equity is costly, building up equity by retaining earnings over time allows to avoid these costs.[7]

I define as direct issuance costs all the fees and costs that the bank needs to pay during the issuance process (Corporate Finance Institute (2023)). These include fees paid to the underwriting investment bank, to accountants and notaries to prepare legal forms and to authorities like the SEC. Fees are also paid to the underwriter for marketing activities that are aimed at selling the securities successfully and at the highest possible price.[8]

Determinants. These fees depend on a variety of determinants, including the type of offering. According to Burkart and Zhong (2023), offering modes can be categorized broadly into rights offerings, public offerings and private placements. The authors explain that in the former, current shareholders receive short-term options to buy additional shares on a pro-rata basis, where the price is set below the market price to incentivize the purchase. This option can typically be sold to other investors. In public offerings, both current and new potential shareholders can subscribe to the issue. Private placements refer to issuances where the new shares are sold to a small group of investors. Eckbo (2008) documents an evolution away from rights and towards public offerings for both financial and non-financial

[7] A friction that breaks Miller and Modigliani (1961) in a similar way is the taxation of dividends. It incentivizes firms to withhold profits rather than distributing them, sometimes referred to as the "retained earnings trap" (Auerbach (2002)). Like issuance costs, this leads to equity issuance avoidance in steady state. However, the focus here is on the dynamic response to tightenings in CR, which differ between the two frictions. Banks facing the need to deleverage will not be disincentivized from issuing equity by the existence of dividend taxes.

[8] Note that underpricing is not included in this definition of direct issuance costs and will be discussed in subsection 2.3.2.

firms, a finding we will come back to in subsection 2.3.4. This shift is despite the issuance costs for rights issuances being substantially lower, for instance due to the reduced need for marketing measures. A subtype of public offerings are accelerated offerings, which have become common in recent years, but mostly among small issuers (Bortolotti et al. (2008), Gunay and Ursel (2015)) and leave out the marketing activities. Gao and Ritter (2010) establish that issuers trade off costs paid for marketing and the elasticity of the demand curve at the offering, a finding which becomes relevant also in subsection 2.3.5.

Another factor shaping the size of direct issuance fees is the choice of the underwriter who conducts the placement. There is a large literature on issuer-underwriter matching in securities markets for non-financial firms (see Carbó-Valverde et al. (2017) for a survey), and a small one on bank issuers (Carbó-Valverde et al. (2016)).[9] According to Becher et al. (2021), the relevant matching categories are expertise and reputation of the underwriter. For instance, Carbó-Valverde et al. (2016) analyse the matching with bond underwriters of European banks and find that after controlling for endogeneity in the matching, underwriters with a better reputation obtain lower yields but charge higher fees. Krigman et al. (2001) find that issuers switch underwriters to move on to underwriters with higher reputations and to obtain more influential coverage from the new lead underwriter's analysts. Besides depending on the quality of the underwriter, fees also depend on issuer characteristics affecting the expected required underwriting effort (Altınkılıç and Hansen (2000)). For instance, the existence of a credit rating for the issuer is associated with lower fees in a sample of non-financial firms (McBrayer (2019)).

In sum, there appears to be a tradeoff between direct issuance fees and the price at which the new shares are sold, a tradeoff we will come back to in the following section.

[9] The authors focus their own empirical analyses on debt issuances, pointing to the rare occurrences of equity issuances in their sample periods. Banks in their sample of publicly traded commercial and investment banks in the US from 1979 to 2014 access equity markets 388 times in total, while debt markets are accessed 15,983 times. Therefore, the status quo of banks' reluctance to issue equity contributes to the gaps in knowledge about decisions related to the issuance decision.

Finally, besides the issuer's choices, fees are also driven by the level of competition between underwriters. While there appears to be competition, this has not been on fees but on other deal characteristics (Chen and Ritter (2000), Gunay and Ursel (2015)) and higher fees are charged by underwriters in the US than in Europe (e.g. Chen and Ritter (2000), Abrahamson et al. (2011)).

2.3.2 Adverse selection

Mechanism. This mechanism is often referred to in the banking literature as a reason for costly equity issuance (e.g. Dagher et al. (2020), Bolton and Freixas (2006), Braouezec and Kiani (2021)). It rests on the adverse selection problem arising from the endogenous equity issuance decision of the firm in the presence of information frictions (Myers and Majluf (1984)). Under asymmetric information about the value of a firm's existing assets, the market may not correctly value its shares. Upon deciding whether to raise outside equity, the firm manager will consider whether the market is over- or undervaluing the shares. Under Assumption 1, the maximization of current shareholders' value, the manager may avoid tapping the market in the case of undervaluation even if this implies that the firm will forego projects with positive net present value (NPV). In the case of a bank required to increase its capital ratio, the bank manager may prefer to adjust its leverage by shrinking the balance sheet through asset sales and to grant fewer loans, rather than issuing equity.

Additionally, potential investors anticipate the managers' strategy. If the manager does decide to issue equity instead of renouncing on the investment opportunity, this is interpreted as a negative signal by potential investors, along the lines of the market for lemons of Akerlof (1978). Therefore, this mechanism stipulates that the share price decreases upon the issuance announcement. Even if equity is issued (extensive margin), the manager is incentivized to keep the issuance intensity low (intensive margin). In the case of the bank facing tighter capital regulation, this could lead to a dampened credit extension in the short run.

Over time, inside equity would allow to build up capital irrespective of the stock price. This dynamic consideration was already pointed out by Myers and Majluf (1984), giving rise to the pecking order theory of corporate financing. In the application to regulated banking activity, this dynamic shift in adjustment tradeoffs would allow to expand the bank's assets gradually as earnings are retained, leading to a non-monotonous lending response.

Note that the issuance of undervalued shares due to asymmetric information is often referred to as dilution (e.g. Heuvel (2002)). From the perspective of an existing shareholder, the additional shares imply that her claims on the firms' profits are reduced, since profits are paid out on a pro-rata basis. On the other hand, the collected cash does not balance out this dilution of claims due to the underpricing.[10] This dilution of claims is to be contrasted from the dilution of control discussed in subsection 2.3.4. We now turn to the prevalence of the adverse selection channel in practice, with a special focus on the banking sector.

Announcement effects. The theory by Myers and Majluf (1984) gives rise to testable implications for stock price movements. A large literature has studied the theorized negative announcement effects of SEOs for decades (e.g. Asquith and Mullins (1986), Ritter (2003) and a recent survey by Veld et al. (2020)). According to Eckbo (2008), announcement effects account for a large part of issuance costs, in the sense that they are large relative to the costs discussed in the previous subsection.

However, the evidence on the announcement effects of banks' equity issuances is mixed. In a sample of UK SEOs between 2003 and 2012, Dissanaike et al. (2014) find that the main drivers of announcement returns during the crisis were uncertainty and macroeconomic conditions rather than asymmetric information. According to the authors, this interpretation arises because distressed rather than overvalued firms issued equity in their sample. Importantly, they find that announcement returns for banks are often positive.

[10] The firm may still decide to issue equity if the positive NPV of potential projects is sufficiently large.

This suggests that the market interprets the issuance announcement as a positive signal rather than one of overvaluation. Another study unsupportive of adverse selection as a main driver of equity issuance decisions is Krishnan et al. (2010). The authors find that the announcement effects on banks share prices are unchanged by the introduction of more stringent monitoring requirements, which suggests that asymmetric information is not a main driver of these stock price dynamics. Contrasting evidence is presented by Botta and Colombo (2019), who analyze the SEOs of banks in western European countries from 2008 to 2014 and find negative announcement returns.

The interaction of capital regulation and adverse selection is also examined in the literature. Li et al. (2016) compare announcement effects of US commercial banks and non-banks and find that abnormal stock returns in the aftermath of SEO announcements are significantly higher for banks, confirming an old finding by Polonchek et al. (1989). Li et al. (2016) point to bank regulations as a potential reason for this difference, arguing that such regulations reduce the likelihood that equity issuance announcements signal overpricing. However, as argued by Admati et al. (2018), this only holds if equity issuance is mandated as an adjustment channel instead of allowing bank managers discretion in this regard.[11] In a cross-country estimation, Li et al. (2019) study the interaction between bank regulation and SEO announcement effects. They find an inverted U-shaped relationship between capital regulation and SEO announcement effects for voluntary issuances. Importantly, in the case of involuntary equity issuances, bank regulation stringency has no significant impact on announcement returns, underscoring the hypothesis by Admati et al. (2018). This last finding underscores the role of asymmetric information on the issuance decision of banks. More precisely, it shows that investors interpret non-mandated issuance announcements as signals of valuation differentials, while this asymmetric information effect is muted for mandated issuances.

[11] We will return to this point in the discussion of policy implications in section 2.5.

Extent of information asymmetry. While studies of announcement returns test the implications of adverse selection, there are also studies that examine its core assumption. For an international sample of non-financial firms, Bessler et al. (2011) find that information asymmetry is indeed a predictor of equity issuances and that they use windows of undervaluation to build up reserves. Similarly, more intensive coverage by analysts is found to lead to more equity issuance, consistent with an alleviation of information asymmetry (Chang et al. (2006)).

As indicated in the previous section, firms face a tradeoff between higher fees and less underwriting when choosing their underwriter. The matching with a costly but reputable underwriter allows firms to limit adverse selection costs, since the underwriter is seen as certifying the value of the shares (Eckbo (2008)). Relatedly, Bortolotti et al. (2008) document a rise of accelerated SEOs, which skip marketing measures by underwriters. They view this as an instance of the "commoditization" of those financial transactions that exhibit relatively low asymmetric information. Eckbo (2008) establishes that while such accelerated offerings have become common also in banking, accelerated SEOs are less widespread for financial institutions than for other sectors. This could indicate that opacity is a more severe problem in banking than in other sectorsn (e.g. Mehran et al. (2011)).

More studies provide bank-related evidence on asymmetric information. Laeven and Levine (2007) find that financial institutions engaged in a variety of activities are valued lower by the market than what is the combined value of hypothetical specialized institutions, which could be due to opacity arising from complexity. Using a calibrated model, Dai et al. (2019) demonstrate that banks' accounting asset values may hide about one third of true asset return volatility arising from nonperforming assets. Thus, accounting asset values are imperfect signals of true value. (Flannery et al. (2004), Morgan and Stiroh (2001)). In turn, voluntary capital adequacy disclosures effect lending positively by making funding less costly for banks (Zelenyuk et al. (2021)).

Summing up, the theoretical case for the adverse selection channel in the banking sector is strong, but empirical evidence from studies of announcement returns is mixed. This could be due to a low importance of this channel relative to other determinants of equity issuances in times of crisis.

2.3.3 Debt overhang

Mechanism. Debt overhang is another friction that is referred to in the literature (e.g. Dinger and Vallascas (2016), Gropp et al. (2019) on financial firms) as disincentivizing equity issuance. The basic mechanism of debt overhang (Black and Scholes (1973), Myers (1977), Gertner and Scharfstein (1991)) rests on the agency conflict between shareholders and debtholders that arise once debt is in place: a part of the benefits of reducing leverage accrues to debtholders in the form of reduced riskiness of their debt. As a result, shareholders may prefer to forgo investment opportunities with positive NPV instead of issuing equity to finance these investments. In the case of banks, this is often referred to as underlending (e.g. Bahaj et al. (2016)).

In a more recent contribution to this literature, Admati et al. (2018) generalize the conditions under which debt overhang arises. They also establish the so-called leverage ratchet, which describes that firms do not only avoid deleveraging, but are simultaneously incentivized to increase leverage over time. This finding can serve as a rationale for capital regulation. Crucial for our purposes, however, is the interaction between debt overhang and capital regulation. How does debt overhang shape the equity issuance and lending responses of banks to tightened CR? I discuss two papers that make predictions for this scenario.

Based on first considerations by Admati et al. (2012), Admati et al. (2018) extend their model to analyze the optimal policies of firms that are required to deleverage. They first derive an indifference result between asset sales and equity issuance: when there are no transaction costs of issuing equity or selling assets, there is only one type of overhanging debt and assets are valued correctly (i.e. sales have zero net present value), shareholders resist leverage reductions through both approaches equally. The intuition for this is that since assets are valued correctly, bank value is not affected by asset sales. It is only affected by the change in leverage, which is necessarily the same for both policies due to the mandated deleveraging. Over- or undervaluation of assets will push the bank to prefer asset sales or equity issuance, respectively. Importantly, Admati et al. (2018) then show that beyond NPV considerations, a variety of conditions are individually sufficient in their setup to bias banks towards asset sales over equity issuance.[12] They also show that asymmetric information about asset quality is likely to bias banks in favor of asset sales when assets are not homogenous.[13] In total, the analysis by Admati et al. (2018) suggests that equity issuance may be avoided for recapitalizations even if the only other alternative are fire sales along the lines of Shleifer and Vishny (2011).

At first glance, the paper by Bahaj et al. (2016) seems to come to a contradictory conclusion. In a model where the choice variable of banks is new lending instead of asset sales, the authors find that higher CR can alleviate the underinvestment resulting from debt overhang, leading to increased lending activity.[14] In their model, this result arises for sufficiently high values of CR. While not discussed by the authors, the intuition for this result rests on their modeling assumption of decreasing marginal returns to new lending. In its decision whether to meet the new requirement through equity issuance or lending cutbacks, the bank faces a tradeoff. On the one hand, it avoids equity issuance due to debt overhang, as discussed above. On the other hind, cutting back lending is associated with opportunity costs. For sufficiently strict capital requirements, complying to these requirements by renouncing on

[12]Sufficient conditions are multiple classes of debt and asset heterogeneity.

[13]They show that if asymmetric information affects on assets is present not only on equity but also on asset markets, and all assets are affected equally by this incomplete information, indifference between asset sales and equity issuance arises as before. Yet, if assets are not homogenous, which is the more likely case in practice, banks can first sell those assets with lower information asymmetries, which implies that shareholders gain from asset substitution.

[14]In their full model, the authors consider how the effects from debt overhang interact with those of risk-shifting incentives arising from implicit debt subsidies due to government guarantees.

new lending opportunities becomes preventively costly as a result of the Inada condition on the assumed lending function. Therefore, further marginal increases in capital requirements are met with equity issuances. This result can be reconciled with the theory by Admati et al. (2018): essentially, it is a special case of the baseline indifference result stated above, in which the bank's deleveraging preferences are determined fully by the NPV of the asset sales. The case considered by Bahaj et al. (2016) is equivalent to the case of undervalued assets, whose sales yield a negative NPV to the bank just like the opportunity costs of new lending.

Based on these theoretical predictions, the two main points for our discussion are the following: Firstly, in the present of installed debt, there is a theoretically derived bias towards asset reductions as a method of deleveraging. This gives weight to debt overhang as a potentially relevant mechanism for a temporary lending cutback. In the long run, after having reduced its balance sheet to comply with the new regulatory requirement on impact, the bank has an incentive to use retained earnings to expand profitable lending activities again. Secondly, the result that asymmetric information breaks the indifference result indicates that debt overhang may interact with the adverse selection mechanism discussed in the previous subsection.

Debt overhang in the banking sector. Debt overhang in non-financial firms and its effect on the macroeconomy have been a widely researched topic recently (e.g. Kalemli-Özcan et al. (2022), Jordà et al. (2022), Jungherr and Schott (2022)), as well as its implications for debt dynamics (e.g. DeMarzo and He (2021)). Regarding the banking industry, Dinger and Vallascas (2016), in reference to Admati et al. (2012), argue that the debt overhang problem could be particularly severe in the banking sector. This is due to leverage ratios that are typically higher than in other sectors, which holds true even under the current levels of capital regulation. One may object that deposits, which make up the majority of bank liabilities (Jermann and Xiang (2023)), are claims on outside money that can potentially be withdrawn at any time. This would allow depositors to walk away from banks that take actions at their detriment. Three arguments mitigate this objection: firstly, deposits are typically not withdrawn for extended periods (Jermann and Xiang (2023)), which may be due to switching costs (Deuflhard (2018)). Secondly, deposit insurance turns bank depositors into inattentive creditors (Iyer et al. (2012)). Finally, deposits are senior to other forms of debt. These arguments reinforce the assessment that debt overhang is likely to be more severe in banking than in other sectors.[15]

Some empirical studies test the theoretical predictions derived from debt overhang, which they do by differentiating between banks with relatively high and relatively low leverage ratios. This rests on the prediction that the implications of debt overhang are expected to be stronger for weakly capitalized banks, i.e. those with lower capital ratios. Ben-David et al. (2019) examine whether in accordance with debt overhang, weakly capitalized banks avoid leverage decreases. In their analysis, they consider two distinct crisis periods, 1985-1994 and 2005-2014, and find that distressed banks do reduce their leverage. In further contrast to the main predictions of the debt overhang mechanism, these banks increase their capital ratios not only through asset reductions, but also through equity increases. Similar findings are presented by Khan and Vyas (2015), Elyasiani et al. (2014) and Botta and Colombo (2019). However, Dinger and Vallascas (2016) argue that the issuance incentives for banks may depend on the existence of a crisis. They conduct a cross-country study covering bank SEOs between 1993 and 2011, therefore not restricting the sample to crisis periods. The authors find that also in this sample, poorly capitalized banks are more prone to issue equity than better capitalized ones. Like the crisis-specific studies, they also find that poorly capitalized banks prefer SEOs over decreases in assets. The authors interpret this as evidence that market pressures to issue equity dominate disincentives from debt overhang.

[15] One context in which debt overhang is discussed as a crucial force in the banking sector is sovereign debt. See e.g. DeMarzo et al. (2023), Acharya et al. (2012) and Occhino (2017) for models in which bank lending is distorted by sovereign debt overhang.

Interactions of debt overhang and capital regulation are also examined by some researchers. In contrast to the previous results, the findings by Gropp et al. (2019) are consistent with the debt overhang mechanism. They use a difference-in-difference matching approach to estimate the effect of capital regulation that was not uniformely tightened on treated banks. Their findings suggest that banks with more subordinated debt and therefore more severe debt overhang are more prone to reduce assets instead of issuing equity. Bahaj et al. (2016) test their theory's predictions that lending is less sensitive to CR tightenings when existing assets are healthy and prospective lending activity yields high returns. They empirically validate their theory in a sample of UK banks from 1989 to 2007.

Summing up, while theoretical arguments suggest that debt overhang is likely to be strong in the banking sector, empirical results about its effect on banks' issuance decisions tend to find no evidence in support of this mechanisms. On the other hand, some studies of the theoretical predictions regarding its interaction with capital regulation have found supportive evidence.

2.3.4 Control dilution

Mechanism. This mechanism is not frequently referred to as a reason for hesitant equity issuance in the bank regulation literature, an assessment also made by Hyun and Rhee (2011). The authors refer to Onado (2008) for having pointed to it. Later, it was empirically investigated by Lepetit et al. (2015) and Goetz et al. (2020). Admati et al. (2018), in their discussion of the implications of debt overhang, explicitly abstract away from the governance issues that give rise to this mechanism.[16] A likely reason for other studies of bank regulation not mentioning the possibility of this effect is its dependence on heterogeneous shareholders, which are not a standard modeling ingredient for tradeoff models of the capital structure. But the prerequisites and implications of control dilution reluctance for firms' financing

[16] "While potentially important, we do not consider the governance issues associated with the decision to default, issue shares, or make a rights offering." (Admati et al. (2018), p.154)

decisions are widely analyzed by a strand of the corporate governance literature dealing with private benefits of control (PBC).[17]

The key idea is that shareholders owning blocks of shares that surpass a certain threshold are presumed to have some control over the firm.[18] This control allows them to enjoy rents, i.e. PBC, consisting of wealth transfers and distorted firm policies (Dyck and Zingales (2004), Morellec et al. (2018)). To what extent rent extraction is possible depends on the quality of corporate governance (Mehran et al. (2011), Dyck and Zingales (2004)).[19] Holderness (2018) points out that shareholder approval of equity issuances is mandatory in some countries but not in others. While rights offerings do not require shareholder approval in the US, they do in most other countries. Therefore, capital structure decisions may also be directly affected by the legal context.[20]

Given PBC, controlling shareholders have an incentive to protect their controlling position in the firm and therefore dislike the public offering of shares (Barclay and Holderness (1989), Doidge et al. (2009)). However, in order to sufficiently explain the empirical observation of hesitant equity issuance, one needs to pose the question why controlling shareholders do not simply buy the new shares themselves. As discussed above in Subsection 2.3.1, this can be facilitated by rights offers, which consist of options to buy shares that are costlessly granted to existing shareholders. But even in the case of public instead of private offerings one would expect controlling shareholders to be the buyers of new shares in a frictionless primary market. The reason for this is that PBC would imply a higher willingness to pay by blockholders than other shareholders.[21] Consequently, in order for control dilution

[17] These are even referred to as a "centerpiece" of corporate finance by Dyck and Zingales (2004).

[18] Edmans and Holderness (2017) advocate definitions of control other than the 5% ownership threshold embedded in US regulations. In a similar spirit, Coates and Scharfstein (2009) refer to this threshold as the "presumption of control".

[19] See Edmans and Holderness (2017) for a review of the theoretical and empirical literature on the role of blockholders for corporate governance. For a recent meta-analysis of blockholders' private benefits of control see Solarino and Boyd (2020).

[20] The role of legal settings in shaping shareholder dilution is discussed in more detail by Calvi (2021), while Holderness (2018) studies the implications for announcement returns and issuance modes empirically.

[21] It is exactly this price premium on shares which is detected by studies quantifying PBC (e.g. Barclay

reluctance to shape the issuance decisions, frictions or additional portfolio considerations shaping the controlling shareholders' supply of outside equity are a necessary prerequisite. We will turn to research on such considerations and constraints in the following subsection.

Note that control dilution is distinct from the dilution of claims arising from the adverse selection problem discussed in 2.3.2 above. Control dilution does not rest on asymmetric information as a driver of differences in share valuation between incumbent and potential shareholders. Instead, it rests on differences in share valuation due to asymmetries in control derived from a share. However, control dilution may be exacerbated by information asymmetries. Firstly, in our discussion of bank regulation, underpricing would imply that more shares need to be issued in order to reach a certain value of outside equity. Given that shares are not proportionally absorbed by current shareholders in the case of control dilution, the lower share price entails a larger number of shares that needs to be issued, intensifying the control dilution. Secondly, bank opacity increases PBC (Jiang et al. (2016)), further increasing the stakes for controlling owners.

Blockholder and insider ownership. Control dilution reluctance rests on the conflicts of interest between controlling and minority shareholders captured by Assumption 3. However, in the case of insider ownership of firm shares, these can overlap with the principal-agent issues arising between managers and shareholders, Assumption 2.[22] While both of these types of controlling ownership may lead to dilution reluctance, they may have diverging consequences for risk-taking behaviour, as discussed below.

Other interactions between these two types of conflicts of interest are possible as well. Holderness (2018) finds evidence that is suggestive of agency conflicts between managers and shareholders as a driver of control dilution. Examining the choice of issuance mode, he documents that rights offers predominate in settings in which shareholder approval

and Holderness (1989) and Doidge et al. (2009)).

[22] Hwang (2004) empirically decomposes PBC into these two components.

is necessary for the stock issuance decision, while public offers are more common when shareholders do not have a right to veto the issuance decision. Since public offers decrease the equilibrium extent of control dilution (Burkart and Zhong (2023)), such agency issues may contribute to the extent of control dilution resulting from equity issuances.[23]

Private benefits of control. A large empirical literature attempts to quantify PBC and to analyze the relationship between its determinants and consequences. Figure 2.2 gives an overview over variables that are commonly examined in the literature.

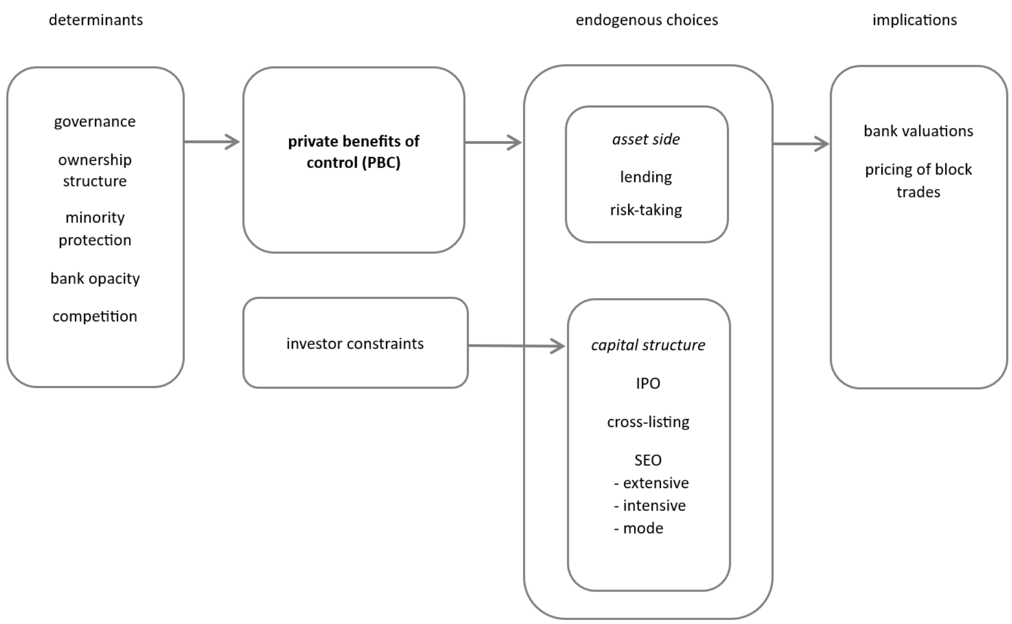


Figure 2.2: Determinants and implications of private benefits of control.

One underlying assumption of the dilution reluctance mechanism is that PBC exist and are economically significant. A common approach to quantify them is to quantify the premia at which block trades are priced relative to other trades (for results on non-financial firms see e.g. Barclay and Holderness (1989), Dyck and Zingales (2004), Albuquerque and Schroth (2010) and more recently Breugem and Corvino (2021) employing a structural model). A similar approach by Guadalupe and Pérez-González (2010) exploits price differences between

[23]However, in that case, the dilution reluctance theory would not have traction as a driver for the reluctance to issue, since managers would implement the issuance against the shareholders' interest.

share types of firms with dual-class shares. These papers often also exploit variation in potential determinants of PBC like ownership concentration, competition and minority protection rules to estimate their effect on transaction premia.

One dimension in which blockholders' and insiders ownership preferences may divert from those of other shareholders is with regard to risk-taking. Such diverging preferences increase the PBC and have been established for financial firms. Here, the differentiation between insiders and other blockholders matters. The findings by Saunders et al. (1990) suggest that manager-controlled banks take less risks than those controlled by shareholders, which can be rationalized by large pecuniary and non-pecuniary PBC that managers obtain from the survival of their bank. In contrast, more concentrated ownership by blockholders is associated with increased risk taking (Laeven and Levine (2009), Beltratti and Stulz (2012)), which can be rationalized by limited liability and lower risk aversion of wealthy blockholders relative to other shareholders.[24]

The PBC in banking may be shaped by banking-specific governance issues, as argued by Mehran et al. (2011). They point out that banking is special due to incentives for risk taking and the resulting need for regulation, as well as opacity. Such asymmetric information is likely to increase PBC since it hampers governance by non-insiders (Jiang et al. (2016)). Mehran et al. (2011) point out that there is little evidence on the effect of laws and regulations on the governance of banks. Exceptions are the analyses by Caprio et al. (2007) and Gianfrate et al. (2012). The former examine the effect of minority protection on bank valuations in an international sample of banks. They find that stronger protection is positively associated with bank valuation, suggesting that PBC can be curbed by such measures. Gianfrate et al. (2012) conduct a classical analysis of block transaction premia in a cross-country study of banks. Their findings suggest that certain law regimes are

[24] A big literature on the relationshop of bank ownership structure and risk-taking, bank stability and non-performing loans confirm these results. See e.g. Fahlenbrach and Stulz (2011), Boussaada (2021),Shehzad et al. (2010), Iannotta et al. (2007), Bouvatier et al. (2014),De Nicolo et al. (2006), De Nicolò and Loukoianova (2007).

associated with lower PBC than others, while a variety of bank regulation indicators does not have a significant impact on transaction premia.

The paper by Aman and Miyazaki (2009) employs a different strategy to detect evidence in favor of PBC in the banking sector by analyzing the share price effects of private equity placements. They find that the valuation effect of private equity placements is less negative when shares are placed with multiple purchasers than with a single one. The authors attribute this to the potential entrenchment effect of large blocks of shares with single shareholders.

Finally, control dilution interaction may interact with the leveraging incentives from debt overhang discussed in the previous section. However, it is debated whether leverage increases the scope for tunneling by shareholders (e.g. Claessens and Fan (2002)) or is a disciplinary tool that decreases it (e.g. Jensen (1986)).

Effect of ownership on capital structure. The previously discussed findings on the existence of PBC in the banking sector provide a necessary condition for any control dilution reluctance. In turn, two studies directly examine our mechanism of interest more directly by gauging the effect of ownership structure on capital structure choices in the banking sector.[25] Goetz et al. (2020) ask whether insider ownership was a determinant of the equity issuance decision of banks during the global financial crisis. The presented evidence is in line with the control dilution reluctance mechanism in the sense that banks with larger insider ownership are less prone to issue shares. The study by Lepetit et al. (2015) complements this finding by looking at banks' controlling shareholders rather than insiders. They evaluate whether asymmetry between control and cash flow rights predicts banks' issuance policy.[26] The authors find that in the case of no asymmetry, banks increase their

[25]Results on non-financial firms include studies on the decision to go public (Helwege and Packer (2009)) and subsequent control dilutions (Kriaa and Hamza (2021)) as well as voting premia as predictors of firms' decisions to cross-list in the US, which decreases PBC by increasing minority shareholder protection (Doidge (2004), Doidge et al. (2009)).

[26]Such asymmetries can arise from dual-class shares with differential voting rights.

capital ratios by issuing equity. In contrast, in the case of asymmetry, i.e. when control rights of dominant shareholders exceed their cash flow rights and PBC are large, banks reduce lending instead.[27]

Besides the extensive issuance decision, some models endogenize the choice of issuance mode conditional on issuance (e.g. Eckbo (2008), Burkart and Zhong (2023)). The tradeoffs in these models rest on current shareholders' wealth or liquidity constraints. Eckbo (2008) argues that the increased availability of low-cost diversified investments may have decreased investors' willingness to hold large stakes in single firms. While not modeled explicitly, such constraints are therefore likely to arise from endogenous portfolio choices. The author documents a global trend from rights offers to public offers, which in his model is rationalized through the decreased shareholder willingness to take up additional shares in rights offerings.

Summing up, while the control dilution reluctance mechanism itself is not a widely studied one in the banking context, the available evidence suggests that one of its key determinants, concentrated control, is a driver of extensive and intensive issuance decisions. Evidence on the pricing of banks' block trades as a measure of PBC are in line with these results. Current shareholders' exogenous or endogenous equity supply constraints are necessary conditions for this channel to gain traction. We now turn to the theoretical and empirical case for such constraints.

2.3.5 Scarce equity supply

Equity supply in theoretical models. The mechanisms discussed so far rest on distortions of the demand for equity by banks i.e. their supply of shares. We now turn to factors that affect the equilibrium issuance of equity through the supply of equity by investors. To illustrate, first consider the contrasting modeling of investors into debt instruments. These are often assumed to have "deep pockets" and to supply financing subject merely to

[27] For the case of non-financial firms, evidence for the control dilution reluctance case similar to that of Goetz et al. (2020) and Lepetit et al. (2015) is provided by Ellul (2008).

a break-even condition given some outside option (e.g. Cooley and Quadrini (2001)) or a fixed price in case of deposit insurance (e.g. Bahaj et al. (2016), Mendicino et al. (2020)). Both of these cases imply perfectly elastic demand conditional on default risk and the equilibrium amount of debt is pinned down by banks' demand. In contrast, theoretical models in both microeconomic and macroeconomic literatures often resort to assumptions capturing the notion that equity supply is scarce or inelastic, at least in the short run.

For instance, Gornall and Strebulaev (2018) and Gale and Gottardi (2020) consider the optimal allocation of scarce equity between the banking sector and corporate sector. In macro-banking models (e.g. as surveyed by Brunnermeier et al. (2012)), bank capital structure is typically pinned down by binding capital requirements, while the available amount of equity pins down the size of banks or the banking sector. For instance, this setup is found in models dealing with the long-run effects of capital requirements (e.g. Mendicino et al. (2018), Elenev et al. (2021) and Begenau (2020)). A notion of scarce equity is also found in two recent papers which explicitly analyze short- and long-run effects of tightened capital requirements by considering the transition between steady states (Mendicino et al. (2020) and De Nicolo et al. (2021)). In these papers, equity supply is in constrained supply in the sense that the shadow value of bankers and other entrepreneurs exceeds the value of paying dividends, i.e. they always invest all of their wealth into shares. For the parameter values considered by the authors, this arises from segmented investment markets and equity investors' wealth constraints.

Such assumptions are popular shortcuts to restrict the supply of equity in accordance with observed patters while avoiding the need to microfound the underlying frictions.[28] In the following, the aim is to explore to what extent this assumption is likely to capture the actual behaviour of the short-term and long-term supply of equity.

[28] This is not to be understood as a critique of these modeling choices. The author acknowledges that modeling shortcuts are necessary for tractable models and justified in dependence of the considered research question.

Mechanism. If indeed the bank-level supply of equity is inelastic in the short run, it amounts to an additional flow cost of equity for the bank: in order to make sure that additional shares are demanded by investors, the share price needs to decrease, exacerbating the dilution of ownership and control. This would consitute an additional mechanism due to which banks avoid recapitalizing by issuing additional shares, opting for balance sheet reductions instead. The possibility of retained earnings could then be a reason for more elastic equity supply and and uptake of lending activity in the long run at the level of an individual bank. However, such an retention of profits implies that investors receive fewer dividends, which consequently cannot be invested into other assets, including other banks' equity. Therefore, it is necessary to consider both the bank-specific and aggregate levels when discussing these questions.[29] Since few papers consider this question with a particular focus on bank securities, I will give an overview over literatures addressing this question in general, pointing out banking-specific studies.

Finally, note that current shareholders constrained willingness or ability to demand additional shares, was discussed as a prerequisite for control dilution mechanism discussed in the previous section. Since current investors are a subset of potential investors, such constraints constitute a subset of factors contributing to the aggregate demand for shares.

Partial equilibrium considerations. A number of literatures examine the downward-sloping demand for individual stocks. According to Jain et al. (2019), this question has been debated in the finance literature for many decades. According to the authors, early empirical studies suggested perfect substitutability even in the short term (e.g. Scholes (1972)), while subsequent research found short-run price pressure (e.g. Harris and Gurel (1986)). Such temporarily downward-sloping demand may be due to slow-moving capital arising from market illiquidity (e.g. Grossman and Miller (1988), Duffie (2010), Acharya

[29] Given some limited availability of equity, dividend taxation could be another friction that may aggravate supply shortages by giving firms an incentive to retain earnings instead of paying out dividends. However, the leverage ratchet considerations by Admati et al. (2018) and high leverage rations in the banking sector imply that this is not a dominating force in banks' leverage decision.

et al. (2009)). Hanselaar et al. (2019) find that, after controlling for measures of asymmetric information and capital market conditions, the market liquidity of firms' shares positively affects their issuance decision. This finding is confirmed for banks by Black et al. (2016). Besides liquidity considerations, the legal setting could also impact short-run equity supply to banks in cisis times.[30] And as indicated in the discussion of direct issuance costs, the demand for bank shares issued in SEOs can be positively affected through underwriter marketing (e.g. Gao and Ritter (2010), Huang and Zhang (2011)), which can be interpreted as an effect on the slope of the equity supply curve.

A large literature employing the stock market effects of index weights adjustments (e.g. Shleifer (1986), Kaul et al. (2000), Chakrabarti et al. (2005)) suggests that stock demand is inelastic not only temporarily, but also in the long run. According to Jain et al. (2019), this results rests on potential shareholders' heterogeneous views of firm value and therefore reservation prices (e.g. Bagwell (1991)). In Bagwell (1991), the previously discussed private benefits of control are a reason for such heterogeneous valuations.

General equilibrium considerations. Looking beyond the demand for single assets, there is a literature that examines the role of segmented markets for different assets (e.g. Duffie and Strulovici (2012), Dick-Nielsen and Rossi (2020)). Some models consider frictions which lead to gradual portfolio reallocations between markets (e.g. Greenwood et al. (2018), Vayanos and Woolley (2013)). More specific to banking, Bertsch and Mariathasan (2015) build a model of "equity fire sales". These arise from price externalities and market segmentation, which results in an imperfectly elastic equity supply. Consistent with their

[30] For the US, Coates and Scharfstein (2009) point to the impact of the legal environment in shaping shareholders' ability to inject additional equity into banks in crisis times. Due to the separation of banking and commerce under the Bank Holding Company Act, investors are not able to obtain controlling stakes in both financial and non-financial companies. Given private equity funds' large investments into non-financial activities, they were unable to also acquire controlling stakes of the banks in their portfolio. According to the authors, a relaxation of the regulatory threshold of five percent control shares would have enabled private equity funds to inject additional equity into troubled banks during the crisis. Whether that is a socially optimal change in legislation will not only depend on the potential welfare gains during banking crisis, but also on potential side effects for instance with regard to competition.

theory, some empirical papers find evidence for first-mover advantages in the banking sector (Dissanaike et al. (2014), Botta (2019) and Botta and Colombo (2019)). Bertsch and Mariathasan (2020) argue that such fire sales give rise to welfare-enhancing macroprudential capital regulation, a point we will take up in the following section.

According to Brunnermeier et al. (2021), an old literature on demand systems (e.g. Brainard and Tobin (1968)) has recently been revived by the paper of Koijen and Yogo (2019). Explicitly modeling investor types (e.g. Gabaix et al. (2023), Beck and Jaunin (2021)), such papers can help to explain the dynamics of flows, quantities, and asset prices (Brunnermeier et al. (2021)). Related papers may also be helpful to shed light on the short and long run elasticities of the equity supply in general as well as equity supplied to banks.[31]

2.4 Interactions and identification

Summing up the previous section, the available evidence collected on the distinct channels is condensed in Table 2.1. While the direct evidence on their interaction with capital requirements is sparse, evidence on their key premises and effects on banks' issuance decision is more available and mostly supportive. However, statements about the relative strengths of the channels are difficult at this point. Identification of single channels may also be complicated by interactions between them, which we turn to now.

Potential interactions between the different flow costs of equity are illustrated in Figure 2.3[32] Firstly, the severity of all mechanisms with the exception of debt overhang are affected by a set of endogenous bank choices conditional on its issuance decision. These include the placement method, the choice of underwriter and the demand for marketing by the underwriter. All of these choices affect not only the direct costs in the form of fees. As

[31] They may also be useful to investige possible spillovers of capital regulation due to portfolio rebalancing in the stock market, which may lead to credit demand effects besides those discussed in Appendix 2.A.2.

[32] This section is a collection and systematization of results. All of the relevant papers and interactions are already discussed in the previous sections, and I refer to the respective sections for additional sources and details.

			evidence on		
Mechanism	key premise	premise measured by	premise	issuance decision	interaction with CR
direct issuance costs	fees	observable	observable		
adverse selection	asymmetric information	announcement effects	+/−	+	
debt overhang	leverage	observable	observable	−	+
control dilution	private benefits of control	transaction premia	+	+	
equity supply	downward-sloping short-term demand	first-mover advantage	+		

Supportive evidence indicated by +, contradictory evidence by −. Missing entries indicate lack of corresponding studies.

Table 2.1: Summary of bank-specific evidence.

discussed above they also affect the extent of underpricing necessary to ensure demand in the presence of adverse selection and more broadly the elasticity of equity supply. Also the extent of control dilution can depend on the placement type. In the presence of these frictions, the bank faces a variety of tradeoffs in making issuance-specific choices. For instance, by hiring a reputable underwriter who undertakes substantive marketing measures to place the issue with investors, the bank will be trading off higher fees with less dilution of claims and control.

Secondly, the dilution of control is not only affected by issuance specific choices like the choice of placement mode. Its traction also directly depends positively on some kind of endogenously or exogenously constrained equity supply by current shareholders. The third interaction is also related to control dilution: leverage ratcheting incentives stemming from debt overhang may increase or decrease the private benefits of control, strengthening or mitigating the reluctance of insiders or blockholders to issue equity.

Finally, several of these frictions are positively affected by the existence and severity of asymmetric information about the banks' asset quality. While asymmetric information is the key requirement for the adverse selection mechanism, it affects the debt overhang and inelastic equity supply channels more subtly. As we learned from the model of Admati

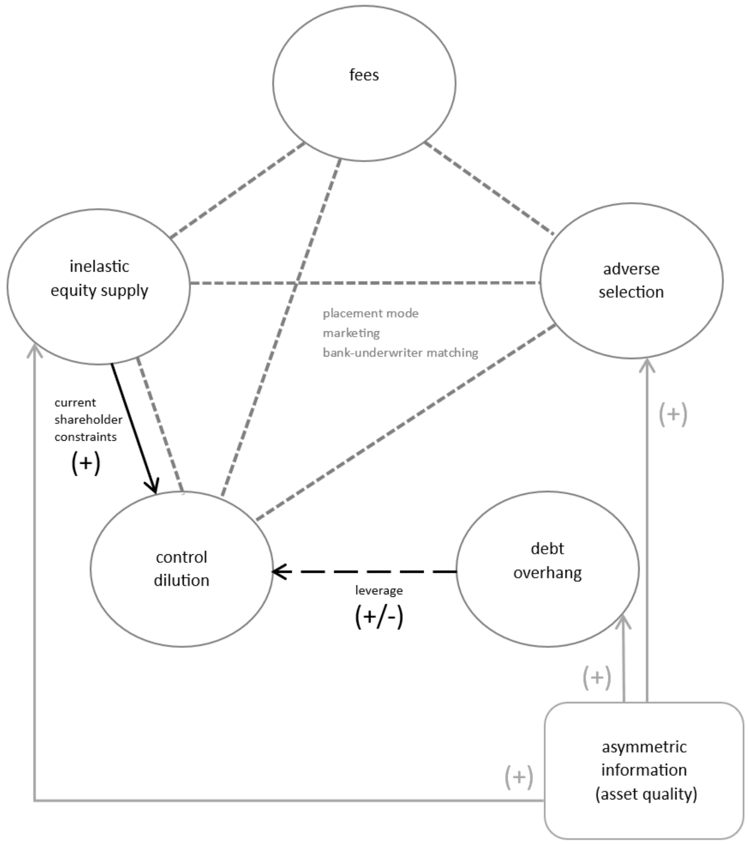


Figure 2.3: Interactions between the flow costs mechanisms.

et al. (2018), asymmetric information regarding asset quality can bias the bank towards balance sheet shrinkage rather than equity issuance. However, it is neither a necessary condition (since other conditions may lead to this bias) nor sufficient (since it may be counteracted by negative net present values of asset sales) condition for the debt overhang channel of the flow costs of equity. Finally, curbing asymmetric information may foster equity supply. While asymmetric information is often taken as reasonably exogenous, there are margins through which banks can influence the opacity of its assets, like discretionary accounting (Bushman (2016)). Taking asymmetric information as endogenous, the bank therefore faces a tradeoff between the benefit of reducing the flow costs of equity and costs that may be connected with the reduction of asymmetric information.[33]

[33]See Acharya and Ryan (2016) for a discussion of the private and social costs and benefits of different accounting approaches.

When it comes to identification of these channels, some structural models have jointly estimated coefficients that approximate the strength of the joint set of issuance frictions. Hennessy and Whited (2007), matching to data of non-financial firms, find equity issuance costs of at least 5% for large firms and 10% for small firms. While the study of Furfine (2000) is matched on bank data, it is more restrictive on the shape of the equity adjustment function. This function is even restricted to be symmetric for negative and positive adjustments, which is not theoretically motivated. Additionally and unlike Hennessy and Whited (2007), it does not match data on equity issuances, but only on balance sheet variables.[34] Using structural estimation to differentiate between the various costs arising from equity issuance would require to model them in an overarching theory and to match data that is informative about the parameters that determine these costs.

Other studies make use of data on banks' equity issuances and their potential predictors, as we have discussed in the previous sections. For instance, Dinger and Vallascas (2016) look at variation in banks' capitalization to find evidence on the debt overhang channel. As discussed in subsection 2.3.3, their results suggest that this channel is not a main driver of the issuance decision. The authors also point out that the determinants of SEOs of non-financial firms are a more widely studied topic in corporate finance than those of banks. It is precisely the rare occurrence of equity issuances that complicates the study of their determinants. However, their study allows to uncover more about the likely drivers of temporary costs from CR tightenings, which are even less frequent. In any case, it will be important to control for macro-financial circumstances. For instance, the study by Dinger and Vallascas (2016) also suggests that large banks are more reluctant to issue equity during a crisis, which is interpreted as a manifestation of bailout expectations. Their finding illustrates that the costs and benefits shaping the issuance decision are likely not constant over time. Beyond bailout expectations, this could also apply to the mechanisms discussed

[34] I am not aware of a structural model that estimates equity issuance costs for banks along the lines of Hennessy and Whited (2007).

here, like asymmetric information and factors shaping the elasticity of the equity supply.

2.5 Policy relevance

Phase-in times. What does the presence of issuance costs imply for banking regulation and policy more generally? The joint significance of these costs, irrespective of the frictions at source, provides a case for phase-in times of capital regulation. Such anticipatory periods allow banks to build up equity through retained earnings, therefore avoiding issuance fees, lemons costs, control dilution and reliance on equity demand by investors, as well as the agency costs arising from debt overhang. This intuition is confirmed in the model by De Nicoló et al. (2023), which includes a general form of equity issuance costs. Sudden tightenings of capital regulation may lead to severe cutbacks of credit. On the other hand, if tightenings are preceeded by anticipation periods, banks react by building up equity through retained earnings, preventing credit crunches.

Empirically, Eickmeier et al. (2018) provide seemingly contrasting evidence. They document that the regulatory tightenings recorded in their sample covering the 1980s and 1990s follow a process in which proposed rules are announced in advance of final rules. The latter then become effective within one to seven months, with the exception of Basel I, which became effective after 23 months. Despite the preliminary regulatory information conveyed by the initially proposed rules, their results suggest that banks react only few months before the final implementation of the tightenings. It is not discussed to what extent this may be due to banks anticipating less severe final rules relatively to proposed rules, and to what extent regulations were revised eventually. Also, in their local projections estimation, allowing for these rather short anticipation effects of four to ten months uncovers bigger and more significant short-run point estimates of tightenings on bank assets and bank loans. Therefore, the relatively short phase-in times in this sample were not sufficient to allow banks to circumvent short run lending decreases by retaining earnings.

In contrast, in the meta-analysis of macroprudential policies provided by Fidrmuc and Lind (2020), the authors find that long implementation periods are associated with higher GDP. Dautović (2020) directly evaluates the impact of the staggered phase-in of capital requirements for European systemically important banks. His results suggest that in contrast to one-off introductions of CR, this approach did not result in deleveraging through asset sales. Finally, the analysis of the Basel III leverage regulation by the BCBS (2022) also provides evidence supporting the case for phase-in times to avoid decreases in lending. Using semiannual data, they find an increase in lending not only in the long run over five years, but also on impact. The authors document substantial phase-in times of the reform for each jurisdiction and note that these may explain the immediately positive impact on lending. This notion is supported by their evidence on the evolution of equity: at the time when the announcement of the reform occured in most jurisdictions, namely the second half of 2014, three quarters of the adjustment of the leverage ratio had already taken place on average.[35] The estimated coefficients on the leads of the reform, which allow to capture anticipation effects, appear insignificant.[36] And most of this adjustment of equity can be attributed to retained earnings rather than equity issuance.[37] Therefore, the long adjustment times of the Basel III regulation allowed banks to employ retained earnings to build up equity and avoid lending cutbacks, while the long-run lending response appears to have been positive in this case.

Thus, while the case for phase-in times of capital requirements seems unambiguous, other policies and areas of intervention depend not only on the joint significance of these costs but also on the frictions from which they arise.

[35]The authors argue that in the case of Basel III, anticipation effects may be relevant even prior to jurisdictional announcement dates since these where precedet by a global announcement of the reform. See Table A1 for the announcement dates of the reform. See Figure 3 for the weighted average of the evolution of leverage.

[36]The point estimates and standard errors for these leads are not reported in the regression output table, Table 10, but Figure A18 suggests that lending is largely flat prior to the announcement date. This holds for both types of banks plotted, above and below median initial leverage ratios.

[37]See Figure 4.

The case for CR in the first place. Four of the discussed frictions make equity costly only in the case of issuance, while not leading to additional costs relative to debt financing once it is on the balance sheet. The exception is debt overhang: it implies that banks have an incentive to ratchet up their leverage (Admati et al. (2018)), which leads to opportunity costs of not deleveraging. Therefore, Admati et al. (2018) make the point that debt overhang rather than other costs is more likely to explain the rejection of more stringent CR among practitioners.[38] Correspondingly, in contrast to the other frictions, debt overhang is likely to contribute to the necessity to impose capital regulation in the first place.[39]

Mandated issuances. Some researchers argue in favor of not only prescribing capital requirements, but of mandating equity issuance. In other words, the regulator would remove the discretion of the bank of choosing its channel of deleveraging, and require it to raise fresh equity. With a focus on crisis-time interventions, this tool may be complementary to regular CR (Greenwood et al. (2017)). Given a crisis episode, some authors see this as a welfare-enhancing intervention for all banks (Admati et al. (2013), Admati et al. (2018), Hanson et al. (2011), Dagher et al. (2020)), while others would employ them on troubled banks only (Coates and Scharfstein (2009), Philippon and Schnabl (2013)). Hart and Zingales (2011) suggest a preemtive issuance requirement to contain credit risk whenever banks' credit risk surpasses a certain level.[40]

Depending on how mandated issuances are implemented, they may yield two potential benefits. Firstly, Admati et al. (2018) argue that they would prevent banks' from selling their assets, which could result in socially costly fire sales that arise since banks do not internalize their own effects on asset prices (Shleifer and Vishny (2011)). This benefit would

[38] The authors also argue that bank owners would profit from requirements as a commitment device ex-ante, i.e. before any debt is installed, since it would reduce the cost of debt. Since incumbent banks are not in this ex-ante state, their rejection of tight CR reflects this time inconsistency.

[39] Besides other frictions that make debt cheap relative to equity as a stock, i.e. once it is raised or retained.

[40] Hanson et al. (2011) point out that this would be anticipated by banks, so that they would likely fire-sell their assets before reaching the threshold.

arise regardless of which frictions are at the source of the equity issuance costs that bias banks towards asset sales.

Secondly, some authors argue that adverse selection on the stock market would not arise if the forced recapitalization is imposed on all banks (Admati et al. (2018), Admati et al. (2013), Hanson et al. (2011)).[41] This benefit from mandated issuances would therefore only arise if adverse selection is a driver of issuance costs. The other costs on banks, stemming from direct issuance costs, control dilution, the removal of debt overhang, and inelastic equity supply, would remain in place. However, the first three of these can be characterized as private costs for the banks rather than social costs. Therefore, such a policy would not necessarily be welfare reducing, even if adverse selection is not the main driver of the flow costs of equity. Social costs to a system-wide imposed issuance policy could arise if the last mechanism, inelastic equity supply, is present. In that case, it is uncertain what types of portfolio reshufflings the policy would entail, which may potentially lead to macroeconomic spillovers.

For the case of imposing equity issuances on troubled banks, Coates and Scharfstein (2009) and Philippon and Schnabl (2013) argue in favor of rights issues as a mode of issuance. Their rationale for this is that public issuances would not be "favourable" for these banks, which again corresponds to adverse selection concerns.

Bank restructuring. In contrast to the issuance mandate, Segura and Suarez (2023) build a model to examine the effect of loan sale requirements in the present of asymmetric information and debt overhang. It is motivated by the observation that liability restructuring solutions have often failed due to asymmetric information regarding the banks' loan books. The reason for this is that banks have an incentive to understate the health of their assets

[41] Dagher et al. (2020) argue that equity issuance is less likely to be "stigmatized" when issuances occur against the background of a system-wide regulation. While this term may refer to the negative signal from the adverse selection mechanism, it may also capture an allusion to irrational behaviour on the parts of investors.

in order to obtain additional concessions from their creditors. The authors show that recapitalizing the bank with the help of a loan sale requirement can help to solve the debt overhang problem. Therefore, if debt overhang and asymmetric information are disincentivizing the bank from recapitalizing, loan sales mandates may be tool that is complementary or a substitute to mandated issuances.

Accounting and reporting. Flannery (2014) asserts that the amount of loss absorption capacity of banks diverges from registered capital levels. According to the author, this is due to generally accepted accounting procedures (GAAP) which focus on book value and can be distorted by managers. Relatedly, Bischof et al. (2020) find that at the onset of the financial crisis, disclosures about risk exposures and loan losses were relatively sparse. This discretion available to managers is likely to increase asymmetric information and, as discussed in the section on interactions above, may therefore aggravate adverse selection, control dilution reluctance as well as equity supply inelasticities. As a result, accounting rules that reduce this opacity are likely to alleviate the flow costs of equity arising from those channels.[42]

2.6 Conclusion

Empirical evidence suggests significant transitory costs of tightening bank capital requirements. This finding can be rationalized by flow costs of equity which disincentivize equity issuance and instead incentivize a buildup of equity through retained earnings over time. I collect theoretical and empirical results on five frictions which may give rise to such flow costs of equity for banks: direct issuance costs, adverse selection, debt overhang, dilution reluctance and inelastic short run equity supply.

Getting a sense of the joint significance of these mechanisms for the banking sector matters:

[42] As pointed out by Acharya and Ryan (2016), there is currently no agreement among scholars and policymakers about optimal accounting schemes for banks.

if these mechanisms in combination are an important driver for banks' capital issuance decision, then short-term lending reductions in the aftermath of regulatory tightenings will indeed overstate long-term changes. This would substantiate the empirical evidence and caution against interpreting results without taking the time horizon seriously.

Taken together, the collected literature points towards some explanatory power of the discussed mechanisms. Direct issuance costs are directly measurable and depend on issuance characteristics that may affect the other frictions. The theoretical cases for the adverse selection and debt overhang channels in the banking sector are strong, but bank-specific empirical evidence is mixed. The reluctance of shareholders to dilute control is empirically supported not only by proxies of private benefits of control in the banking sector but also by studies relating ownership to issuance decisions. Finally, while research on asset demand systems is ongoing, available evidence suggests that there are first-mover advantages in banks' equity issuances, supporting the notion that equity supply is downward-sloping in the short run. Finally, I argue that joint significance as well as the contribution of single frictions matters for the optimal design of banking regulation, including staggered regulatory phase-ins and the case for mandated issuances and loan sales.

2.A Appendix

2.A.1 Evidence on lending effects

Meta-analyses. The relationship of lending and bank capital is widely studied, which is underpinned by a number of meta-analyses of the empirical literature related to this topic listed in Table B.2.

Paper	dependent variable	independent variable(s)	horizons	level
Boissay et al. (2019)	bank lending	capital ratio, CR	transition, long-run	bank
Araujo et al. (2020)	ten outcome variables including credit and GDP	macroprudential policies including CR	<1, 1-2, >2 years	bank, aggregate
Fidrmuc and Lind (2020)	GDP	CR	long run	aggregate
Malovaná et al. (2023)	credit, bank lending	capital ratio, CR	<1, >1 year	bank, aggregate

Table B.2: Meta-studies of bank capital (requirements) and economic activity

Boissay et al. (2019) find that a one percentage point increase in the capital ratio is associated with a reduction in loan growth of 6.9% in the short-term, but a moderately positive effect of 0.4% in the long-term. Note that these are effects on growth rates rather than levels. However, these results are qualitatively equivalent to the impulse response function of Eickmeier et al. (2018) since the positive growth rate would make up for the temporary decrease in losses, leading to a recovery of levels.

While addressing important questions, the remaining meta-studies do not perfectly cover the relevant evidence for the research question of this paper. Each paper's focus deviates more or less from the lending effects of CR tightenings. This implies that the sets of papers included in these meta-analyses include only few studies that immediately explore such lending effects. For example, Malovaná et al. (2023) do not restrict their attention to studies on the effects of capital regulation, but also include studies that use endogenous regulatory ratios as independent variable. Employing a snowball-algorithm for their search of papers, their resulting set of studies covers only five empirical examinations of CR tightenings on lending activity. Given this, they do find evidence corresponding to our hypothesis: studies considering short-term effects between bank capital and lending find more negative effects than those of longer horizons.

Fidrmuc and Lind (2020) examine the effect of CR, but take GDP as a dependent variable. Their finding that higher CR is associated with a moderately lower GDP in the long run is not informative for temporary lending effects, but does suggest moderately lower long run lending outcomes. Araujo et al. (2020) only survey papers with a focus on macroprudential tools in general, and examine a variety of ten different outcome categories and even more outcome variables. As a result, their set of papers reflects a much wider focus and includes only five studies of the effect of CR tightenings on credit-related outcomes (household credit and mortgage credit).

2.A.2 General equilibrium effects.

As discussed in subsection 2.3.5, portfolio reshufflings of equity investors may lead to general equilibrium effects of capital regulation. Of course, this is not the only channel through which the effect on aggregate outcomes may be more than the sum of first round bank lending effects. The VAR estimation by Meeks (2017) yields dynamic responses of aggregate responses to capital regulation. They exploit bank-specific capital requirements that were imposed on UK banks between 1990 and 2008 and identification relies on the institutional setting and timing assumptions.[43] The authors find evidence for a financial accelerator that amplifies macroeconomic responses to reductions in bank credit supply. Relatedly, Eickmeier et al. (2018) examine the transmission mechanism through which GDP is affected

[43]Firstly, the authors argue that the requirements were microprudential, in the sense that they did not response to macroeconomic variables. Secondly, confidentiality of changes made sure that regulations did not affect macroeconomic variables directly, but only through changes of bank lending. Finally, they assume a lag between requirement announcements and changes in bank lending.

by the temporary decrease in bank lending. They find that the lending reduction brings about a temporary decline in investment, consumption and housing, and that these effects are amplified demand effects from reduced household spending that arise from wealth and income effects. In line with the rationale behind capital requirements, these effects are mitigated in the medium term by a decline in risk.

Other papers in which the dynamic macroeconomic effects of capital requirements are shaped by propagation and amplification are Mendicino et al. (2020) and De Nicolo et al. (2021). In these papers, generalized equity issuance costs interact with other financial and nominal frictions to produce responses that qualitatively correspond to the dynamics maintained here. A different type of spillover effects is found in the meta-study of macroprudential policies by Araujo et al. (2020). The explanation offered by the authors is that international banks or non-banks may serve domestic credit demand when domestic banks are subject to tighter regulation, which is consistent with evidence on regulatory arbitrage (e.g. Reinhardt and Sowerbutts (2015)). In this case, the general equilibrium would be muted, rather than amplified.

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