Asymmetric Information, Cash Holdings and Mortgage Renegotiation: Theory and Evidence

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Abstract

The thesis consists of three chapters that investigate the effects and the consequences of information asymmetry on firms' financing decisions and activities.

In the first chapter I review the main papers that researched the asymmetric information problem in the finance literature. In the first paragraphs, I focus on relevant contributions to the signaling theory, analyzing those models that employ as signals the amount of debt held, new equity issues, and dividend distributions respectively, and report the evidences that support or reject their information content. Then, I describe the transition to the game theory approach, which has been widely successful in the years that followed, focusing on three relevant topics in the literature: capital structure decisions, the dividend puzzle, and financial intermediation.

In the second chapter I empirically test the relationship between corporate cash holdings and information asymmetry in R&D intensive firms. Two hypotheses are tested, that cash holdings act as a signal of firm performance (and, therefore, that may decrease the degree of information asymmetry that affects the firm) and that the optimal amount of cash holdings for R&D intensive firms is higher than that of non R&D intensive firms.

The model is estimated using fixed effects, which I deemed to be the appropriate choice given the characteristics of the panel used for the analysis.

In the third chapter I analyze the effects of mortgage renegotiations on social welfare, using a two-period model that is structured as a Bayesian game. I show that, under certain conditions, only a mixed-strategy equilibrium exists, and that renegotiations Pareto-improves total welfare.

Although total welfare Pareto-improves, this is just a result of an increase in the borrower's welfare, while the lender's welfare does not change. Since the lender seeks profit maximization, he has no incentive to reach the highest level of social welfare. Thus, Government should support mortgage renegotiations to achieve that level of total welfare that the market is unable to reach on its own.

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Chapter 1

Information asymmetry in the Finance literature: from the signaling theory to the game theory approach

Abstract

Signaling theory was developed to explain the observed behaviour of subjects that act in situations characterized by information asymmetry. Every signaling model consists at least of a sender, i.e, the agent who transmits the information, usually to obtain some benefits, the receiver, i.e., the agent that is the addressee of the information, and the signal itself, that, to be effective, need to be observable and not easy to imitate by other agents that wish to be confused with the sender. Although signaling theory has been largely used in the corporate finance literature, at least in its initial formulation it lacked the formal structure and the more rigorous analysis which are typical of game theory. In this review we examine the essential characteristics of the signaling theory, the most important contributions to some relevant topics in the literature, and describe the transition to the game theory approach, which has been widely successful in the years that followed.

Introduction

Information asymmetry refers to a situation in which the two parties involved in a contract do not have the same information. It is a market imperfection that usually leads to a loss of welfare for the part with less information (if compared to a situation of complete and symmetric information), and can be the cause of market-breakdowns.

Two different typologies of *information asymmetry* exist: the first is the so-called *adverse selection*, while the second is known as *moral hazard*.

Adverse selection corresponds to a situation in which information asymmetries affects one of the parties before a contract is signed, as it happens in the famous market for “lemons” that Akerlof (1970) developed as an example to show the possible consequences of this type of market imperfection.

Moral hazard, instead, corresponds to a situation in which information asymmetries appear after the signing of a contract. A typical example is the market for car-theft insurances: the insurance companies do not know whether the other part will take all the necessary precautions against thieves, or if her will simply leave the car unlocked on the street.

The effects that information asymmetries have on firms’ activities, both internal and external, have been extensively researched by the financial literature.

Regarding internal activities, information asymmetries may refer to the fact that a firm’s insiders usually have more information about its value and future investment opportunities than outsiders do. As a consequence, the market may not be able to correctly evaluate the firm’s shares, affecting its future investments. A high value firm that is eventually undervalued by investors, because of them not having enough information, will probably avoid raising capital through a new equity issuance. If it does not have another source of capital to resort to, it may be forced to pass future investment opportunities that have a positive NPV. Should it issue new equity regardless, the result of the operation, if the NPV is not high enough, would only be a wealth transfer from old to new shareholders. Therefore, if managers act solely in the interest of old shareholders, information asymmetries may cause *underinvestment*. This is a typical setting in the corporate finance literature.

Information asymmetries may also have repercussions on firms' external activities. This is indeed the case in the banking industry, where banks suffer both from adverse selection and moral hazard.

As showed in Stiglitz e Weiss (1981), adverse selection may cause credit rationing and misallocation: due to lack of information, lenders cannot distinguish between high risk and low risk firms, so they may end up asking for higher interest rate to compensate for the average risk they have to bear. The result, conceptually similar to Akerlof (1970)'s "market for lemons", is that firms with low default-risk, which typically have stable cash-flows, decide not to invest in new projects, while high-risk firms are willing to pay the high interest rate because their project's pay-offs are high in case of success, and they can simply default in case of failure.

Problems related to moral hazard arise after the borrower gets financed, because he may have an incentive to implement certain behaviours that conflict with the lender's interest, as investing in projects riskier than those for which the funding was requested, causing an increase in the default risk the lender has to sustain.

In order to reduce the negative effects caused by information asymmetries, economic agents that possess private information may try to convey them to the other parties through some kind of signal. *Signaling theory*, when applied to the economic field, studies the *signals* that economic agents transmit, consciously or not, to one or more receivers, their characteristics, and the conditions that have to be met to move from a so-called *pooling equilibrium* (that is a situation where there is only one equilibrium price regardless of the characteristics of goods, people or organizations that constitute the object of a transaction) to a *separating equilibrium* (that is the case in which there are two or more equilibrium prices that consider the object's value or characteristics). Although the first formulation of the *signaling theory* was developed using a hypothetical labor market as example, it has been applied in many different fields.

In Finance, the first papers that adopted this approach, as Ross (1977) and Bhattacharya (1979), had the merit of introducing the relevance of information asymmetries in the literature, which was almost completely based on the principle of irrelevance formulated by Modigliani and Miller (1958, 1961) until then. However, a more rigorous and more structured analysis was needed.

In this article we review the main papers that have researched and applied signaling theory to the finance literature and the transition to the game theory approach, which has been largely successful.

1. *Signaling theory*

1.1 Early contributions

For the most part, the papers we analyze in the following paragraphs are affected by *adverse selection*, a situation in which the information asymmetry is present before a contract is signed.

Akerlof (1970) shows the possible consequences of *adverse selection* using the market of used cars as an example. In his article, Akerlof models the market of used cars so that only one car model is available for purchase. Although there is only one car model, car dealers may sell either high quality or low quality used cars. The problem here is that potential buyers do not have the knowledge to distinguish whether a vehicle is of high or low quality. As consequence, assuming they are not risk-lover, the maximum amount the buyers are willing to pay for a used car is the expected value of their purchase. This expected value is certainly higher than the value of the low quality car, but it is lower than the value of the high quality car. As a consequence, the dealers will not sell the high quality car, since they would incur a loss, and will sell only "lemons". The inability of the buyers to differentiate between high quality and low quality cars, and the lack of any signal able to fill the information gap, lead to a *pooling equilibrium*, a situation where there is only one equilibrium price that does not reflect the different characteristics of the goods.

In his article, Akerlof shows that *adverse selection* can be the cause of market failures. However, he also suggests that sellers of high quality cars may differentiate themselves from sellers of low quality cars by offering a warranty, to convince buyers that the vehicles they are selling are indeed of good quality. Sellers of low quality cars may also offer a warranty, so that their cars may still continue to be confused with the high quality ones. To reach a *separating equilibrium*, i.e., a situation in which there are two or more different equilibrium prices that reflect the different characteristics of the goods, the warranty needs to be designed so that sellers of used cars do not have any incentive in offering a warranty. If sellers of high quality can design such a warranty, then they will offer it and they will be able to charge to the customers their cars' value, otherwise it would be uselessly onerous to offer a warranty. However, in the second-hand market the use of a warranty is indeed an effective signal, since it would be too costly to imitate for a seller of low quality cars, which would be asked too often for a refund.

Although in this paper it is already possible to recognize the idea that economic agents may try to fill the information gap through some actions or decisions, the first formulation of the *signaling theory* is due to Spence (1973). Spence, using as an example a hypothetical labour market, shows that signaling may indeed reduce information asymmetry and help the market in reaching a *separating equilibrium.* In his model, the employer does not have information about an applicant's productivity, so that hiring a new employee appears closely related to a random lottery. The more productive applicants would be better off if they could signal their productivity to the employer, because they would earn a higher wage. However, as for the warranty in Akerlof (1970), the act of signaling cannot have any positive outcome if the signal may be easily imitated by the low productivity applicants, because the employer would not be able to differentiate between the two categories. To avoid the possibility that low productivity applicants may imitate the signal, Spence says that the signal's costs need to be negatively correlated with productivity. If this is the case, then low productivity applicants may be better off not imitating those with high productivity and accepting a lower wage, because in this case the cost they have to sustain would be higher than the loss in terms of wage.

Spence argues that *education* may be a suitable signal for an applicant's productivity: it can be observed by the employer, and it is negatively related to productivity, because high levels of education require a great effort that low productivity workers may not be able to endure.

Therefore, in Spence's model high productivity applicants have an incentive in reaching high levels of education, as to differentiate themselves from low productivity applicants, which will not reach the same level of education if the wage structure is appropriate.

1.2 The characteristics of a signaling model

The essential elements of a *signaling model* can be already found in Spence (1973). The first element is the sequential order: the *signaler* (usually an insider that has information that outsiders do not have about a person, a product, or an organization) transmits a *signal* to the *receiver* that observes it first, and then makes a decision.

The second element is the *signal* itself. It needs to have two characteristics to be effective and allow for a *separating equilibrium* to be reached: it has to be observable and costly. Clearly, if the *receiver* cannot observe the signal, then he will not obtain any additional information and will behave and act as the *signal* does not exist. And the *signal* certainly needs to be costly in those cases in which it consists of a certification or a degree, because otherwise it could be easily imitated by those that do not have the skill or the characteristic that the *receiver* requires but that would benefit from being mistaken with those who possess it. To avoid this situation, not only the *signal* need to be costly, but it needs to be increasingly so for those who do not have the required characteristic, or possess it less intensely, so that the benefits obtained from imitation would be offset by these costs.

If these conditions are not met, the *receiver* cannot infer any information from the signal. However, some authors (e.g. Brennan and Kraus, 1987) have built models where, although the signal is costless, it is still possible to reach a *separating equilibrium*.

The last element of a *signaling model* is the *receiver*, the outsider that does not have some information that he needs for making a certain choice or decision, and that want to obtain it. It may happen that the *signaler* and the *receiver* incur in a conflict of interests, since the *signaler* may have an incentive in lying.

Signaling theory has been applied, for the most part, to situations in which the *sender* transmits the *signal* deliberately, as he wants to pass some information to the *receiver*. However, there are situations in which the *signal* is transmitted and received regardless of the *sender*'s intention. This is the case of new equity issues, which usually the market sees as a *signal* of a firm's negative future prospects, because managers have an incentive in issuing new equity if they believe it to be overpriced (Myers and Majluf, 1984): in this case, the *signal* is only an involuntary consequence of another action.

2. *Signaling theory* in the finance literature

2.1 The firm's financing decisions

The Modigliani-Miller Theorem (Modigliani and Miller, 1958) laid the foundation for what can be addressed as the *modern theory of capital structure*. One of its conclusions is that, under some assumptions, capital structure is irrelevant, because financing decisions do not affect the market value of a firm.

More specifically, it is assumed that the market is perfectly competitive, that there are no frictions, that individuals and firms can borrow at the same interest rate, that there are neither taxes nor bankruptcy costs, and that all individuals possess the same information.

This result of *irrelevance* can be obtained because, even though in the model an increase in the firm's leverage cause an increase in the return, this is neutralized by an increase in the risk faced by the firm and in the discount rate that the market use for evaluating it.

This result was so important and well-known that the following literature did not pay the necessary attention to the firm's financing decisions (Stiglitz, 1988). However, Modigliani and Miller were aware that their *irrelevance result* depended deeply on the assumption of symmetric information, and that its violation would cause financing decisions to affect firm value. If the market forms its expectations weighting too heavily past and present performance because of a lack of information about a firm's future new investment opportunities, then the management will probably not finance them issuing new equity, because the current share price would be too low. In this case, Modigliani and Miller affirm that debt financing would be preferable (Modigliani e Miller, 1958).

Stiglitz (1974) is the first that recognize, although indirectly, that a firm's financial policy may *signal* information to the market. He develops a generalization of the Modigliani-Miller model that still exhibits the *irrelevance result*. Among the model's limitation, Stiglitz points out that the *irrelevance result* does not hold if investors (that in this model are the households) modify their expectations about the return of their investment after a change in a firm's financial policy. This observation is the foundation of that strand of literature that applies the *signaling theory* in the corporate finance field.

Financial economists have developed a large number of models that show the problems that may be caused by information asymmetries, and how they could be solved, at least partially, through the management's financing decisions. The reason is that those decisions may have a *signaling role*, and may transmit to the market enough information to reduce the asymmetric information problem.

In the next paragraphs we examine the most important papers that have studied the signaling role of debt and equity.

2.1.1 Debt signaling

All the essential elements of a *signaling model* that we have discussed in paragraph *1.2* can be found in Ross (1977).

In his article, Ross removes the assumption of symmetric information in the Modigliani-Miller model and assumes that managers have more information than outsiders about their firm's value. He designs a rewarding system that it is positively related to the value of the firm, and that consider a penalty fee in case of bankruptcy. Managers act in their own interest and try to maximize their reward.

In this setting, managers of high value firms choose to issue an amount of debt that managers of low value firms decide not to imitate, because the probability of bankruptcy would be excessively high, as the probability of having to pay the penalty fee. Since managers of low value firms desist from imitating those of high value firms and issue a lesser amount of debt, they reveal their type. Therefore, the amount of debt issued is an effective *signal*.

If the market were not able to distinguish between the two types of firms, only a *pooling equilibrium* could be reached. As a consequence, high value firms would be undervalued, while low value firms would be overvalued. Clearly, high value firms have an incentive in signaling their type to the market, and they reach their intent through issuing a certain amount of *debt* as a *signal*. Indeed, as a seller of low quality used car cannot support the cost of a warranty, the management of a low value firm knows that cannot sustain the same amount of debt issued by high value firms, since the probability of bankruptcy would be too high.

Leland and Pyle (1977) develop a model in which the amount of *debt* issued is only an *indirect signal*, since it is used to finance the *real signal*, which is the fraction of equity retained by the manager / entrepreneur.

In this model, information is asymmetrical because only the manager / entrepreneur has enough information to evaluate the new projects and investments that he is planning to undertake, but he has no credible method to convey it to potential investors. He can issue *debt* at the risk free rate both at individual and firm level. Moreover, it is assumed that the manager / entrepreneur is risk-averse, and that he can choose whether to finance its new projects with *debt* or *equity*.

In this setting, issuing more debt (and less equity) is more costly because the manager / entrepreneur is forced to hold a larger share of the firm's equity and to sustain more risks.

Therefore, owning a large share of the firm's equity and issuing high levels of *debt* are two sides of the same coin, and each of them can signal to the market the quality of the new projects that the entrepreneur plans to undertake.

Given the fact that managers / entrepreneurs are risk-averse, and since the risk that originates from owning a fraction of the firm's equity is higher the larger the fraction is, only those entrepreneurs that are going to undertake high value projects will be able to afford the additional risk of owning a large share of equity, while the entrepreneurs whose new projects have low value will issue new equity to reduce their own exposure to risks, revealing the quality of their projects. Therefore, Leland and Pyle hypothesize the existence of a positive relationship between the amount of debt issued and firm value.

Heinkel (1982) builds a model of *costless signaling* where it is still possible to reach a *separating equilibrium*. Since it is *costless*, the parts do not have to sustain any deadweight cost for the *signal*'s transmission, and their welfare is the same that in the case of symmetric information.

Heinkel builds on the positive relationship between firm value and the amount of debt issued hypothesized in Leland and Pyle (1977) and on the positive relationship between firm value and the probability of default presented in Ross (1977), and assumes that the higher is the value of a firm, the higher is its credit risk. As a consequence, high value firms have less valuable, more risky debt than low value firms. Heinkel also assumes that outsiders do not have information on the mean and the variance of the firm's returns. The last assumption is that the manager / entrepreneur can issue risky debt.

In this setting, the amount of *debt* issued is an effective *signal*, even though this model does not consider any penalty for the managers of those firms that go bankrupt.

The deadweight cost that originates from owning a large share of the firm's equity (as in Leland and Pyle, 1977) is avoided by introducing a set of securities that are substitutes for the firm's equity and that can be shorted to eliminate the diversification risk. This feature of the model allows managers to change the capital structure of their firms without costs.

Therefore, under the assumption of the existence of a positive relationship between value and credit risk, the managers / entrepreneurs of high value firms will issue less debt; conversely, the managers / entrepreneurs of low value firms will hold smaller shares of their firm's capital and will issue more debt, contradicting Leland and Pyle (1977)'s conclusions.

The relationship between firm value and credit risk is crucial to reach a *separating equilibrium*, although it is questionable from an empirical point of view.

2.1.2 Empirical evidences on debt signalling

The most important prediction of the models we have analyzed is that firm value should be positively related to the amount of debt issued. This prediction should hold even after dividing both firm value and debt for the firm's *book value of assets*.

However, Rajan and Zingales 81995) and Frank and Goyal (2003) find a negative relationship between *leverage* and *market-to-book*. Also Titman and Wessels (1988) and Fama and French (2002), using the profitability of the firm as a proxy for firm value, find evidences against this prediction. Cornett and Travlos (1989) focus on the long-term performance and find a positive relationship between earnings and leverage.

Another prediction of these models is that managers should change the capital structure of their firm if their expectations differ from those of the market. For example, if the more informed managers expect their firm's value to increase more than the market do, then they should issue more debt as a *signal,* so that the market, who is currently undervaluing the equity of the firm, could adjust.

However, empirical evidences of this prediction are, at best, mixed. Manuel et al. (1993) and Howton et al. (1998) observe a decrease in share prices after the announcement of a new debt issue, while Johnson (1995) finds an increase in share prices after the same type of announcement, although only for those firms with low dividend payments.

2.1.3 Equity signaling

Myers and Majluf (1984) laid the foundation of that strand of literature that focus on the new equity issues' signaling power. The two authors analyze the adverse selection problem that may affect those firms that plan to issue equity to fund new projects if managers have more information about them than the other investors do.

A crucial hypothesis of this model is that managers act solely in the interest of the old shareholders. The consequence of this hypothesis in a setting with information asymmetries is that managers will issue new equity if the market is currently overpricing their firm's shares, but they may give up on projects with a positive NPV if the firm's equity is underpriced beyond a certain threshold, causing *underinvestment*: indeed, if the existing equity is underpriced enough, it may happen that the wealth transfer from old to new shareholder is greater than the profits that old shareholders would earn from the new investment. The rational investor expects this managers' behavior, and reacts negatively to the new equity issue, causing a depreciation of the firm's shares.

Myers and Majluf suggest that the *underinvestment* problem may be entirely solved using internal funds or risk-free debt, since they do not suffer from mispricing, or that it may be partially solved using risky debt, which suffers from mispricing but less severely than equity do.

The main prediction of this model is called *pecking-order theory*. It states that if there are significant information asymmetries, managers should prefer debt financing to equity financing, since it should be less expensive. Internal funds stand at the top, being preferred to both debt and equity financing, since they are generally risk free and do not suffer from information asymmetries.

In this paper, the new equity issue can be seen as a *negative and accidental signal*, meaning that investors retrieve information from the new equity issue that managers were not planning to transmit: it is just the result of the hypothesis of investors' rationality. Investors can decipher and anticipate the managers' maximizing behavior, even though they are not trying to convey any information.

Krasker (1986) builds a two-period model that generalizes the model of Myers and Majluf. He assumes that managers, in addition to choose whether to undertake a new project or not, can also decide the amount of equity that needs to be issued for financing purposes, so that the issue's size is a continuous variable. Krasker goes beyond the prediction of the Myers-Majluf model that new equity issues affects firm value negatively, and predicts a negative relationship between the firm value and the size of the issue.

For this reason, the size of the issue assumes a *signaling role*, and the inverse relationship between it and firm value can be so steep that it is not possible to raise any more capital by increasing the issue's size once passed a certain threshold

Bradford (1987) modifies Myers e Majluf' assumption about managers acting exclusively in the interest of old shareholders, and assumes that they aim to maximize their firm's value.

Moreover, he assumes that managers can trade their firm's shares at the issue price.

It should be noted that the model takes into account both the loss of control over the firm that is the consequence of selling the firms' shares, and of the loss of diversification caused by holding treasury shares.

Bradford shows, consistent with Myers and Majluf, that the firm's value decreases after the announcement of a new equity issue, but in his model equity issues are more frequent because of managers' trades: since managers can make an additional profit by trading their firm's shares when they are underpriced and since they aim to maximize their firm's value, managers need not to issue new equity only when the market is overpricing the firm's shares.

Another prediction of this model is that, if managers can trade their firm's shares, then the firm's value after the announcement of a new equity issue is higher than in the case in which managers cannot trade. The reason is that investors can observe the managers' behavior during the new equity issue, thus retrieving information that allows them to better evaluate the firm, since they can update their evaluation according to the managers' actions.

Lastly, we analyze Brennan and Kraus (1987), that presents a model that allows for a separating equilibrium to be reached through a *costless signal*.

In this model there are two typologies of firms, high and low value. The high value firms' cash flows distribution stochastically dominates that of low value firms. The information asymmetry consists of the fact that investors do not know the firm's typology.

Both typologies have some preexistent debt, but while the debt of high value firms was issued at the risk free rate, that of low value firms has a risk premium.

Given this setting, in this model it is possible for a *separating equilibrium* to be reached after that firms reveal their typology because of some changes in their capital structure. The only condition needed is a restriction to the set of the firm's financing decisions.

In equilibrium, when low value firms have to finance a new investment, they only issue the amount of equity needed for the project, while high value firms issues enough equity both to finance the new investment and to repay their preexistent debt. The equilibrium is stable because neither of the two typologies have any incentive to change their behavior: the high value firms will not reduce the amount of equity issued because they could be mistaken for low value firms, causing their equity to be undervalued; on the other hand, low value firms may imitate the high value firms' behavior and have their equity overvalued by potential investors, but this benefit would be offset by the fact that also their debt that they need to repay would be overpriced.

The model presented by Brennan and Kraus has, therefore, different implications from those of Myers and Majluf (1984): the first is that, despite the presence of information asymmetries, there is no underinvestment; the second is that both firm typologies prefer to issue equity to finance their investment despite the fact they could also choose to issue debt, contradicting the pecking order theory.

2.1.4 Empirical evidences on equity signaling

According to the pecking order theory, the market should consider the announcement of a new equity issue to be a negative signal. As a consequence, announcements should be followed by a reduction in firm value. Conversely, the announcement of a new debt issue should have a less negative effect on firm value, since debt is less affected by information asymmetries.

Kowajczyk et al. (1991) find evidences on the information content of new equity issues. They observe that the reduction in share prices after an issue is positively correlated with the amount of time passed from the last disclosure of information

Jung et al. (1996) find mixed evidences regarding the pecking order theory. Consistently with the theory, they observe a reduction in share prices after the announcement of a new equity issue, while they measure no changes after the announcement of a debt issue, since debt is less affected by information asymmetries. Contradicting the prediction of the pecking order theory, they also observe that large firms issue equity less frequently and resort to debt more often than the average firm, despite the fact that they should be less affected by the asymmetric information problem, because they are followed more closely by analysts.

Also Helwege e Liang (1996) find evidences against it. They focus on those firms that have been listed recently and that, therefore, should be more affected by information asymmetries. These firms are usually quite young, have a high growth rate and insufficient internal funds. The pecking order theory predicts that firms more affected by information asymmetries should prefer debt financing over equity financing, however the two authors observe a preference for new equity issues over bank debt financing.

2.2 Dividend signaling

Some authors have developed *signaling models* to explain the abnormal returns that firms receive after the announcement of dividend distribution. These excessively high returns cannot be explained using perfect information models, considering the fact that, historically, the taxation of dividends has been less favourable than that of capital gains and, therefore, should destroy value.

We begin the analysis on *dividend signaling* with Modigliani and Miller (1961), who first proposed the idea of dividend irrelevance. In this article, the authors build a one-period model where the capital market is perfect, there is no uncertainty, and investors are rational (they prefer higher amounts of wealth to lower) and indifferent between dividend payments and capital gains. It is assumed, moreover, that there are neither taxes nor information asymmetries, and that the current level of dividends cannot affect the future market value of the firm (i.e., current dividends have no information content).

Given this setting, and assuming that firms have the same investment choices, the value of a firm is independent from its dividend policy. According to this irrelevance result, an investor does not need any information on the dividend policy of a firm that he wants to invest into to make his choices. However, it has been empirically observed that the announcement of a dividend distribution is closely evaluated by different types of investors: this should be the result of one or more violations of the model.

Bhattacharya (1979) presents the first *signaling model* in which the signal consists of dividends. In his work he assumes the existence of asymmetric information and formulates a different theory to explain dividend policy. Managers have inside information about the cash flows distribution of the project they intend to undertake, and they can signal it to the market through the choice of the amount of the dividend payments. The cost of the signal is a consequence of the fact that dividend payments reduce the amount of the firms' free cash flows, and therefore increase the probability of having to resort to external financing (which is assumed to have transaction costs) to finance future investments. Hence, it is possible to reach a *separating equilibrium* in which firms with higher expected returns are those that pay the highest dividends

Heinkel (1978), instead, consider a setting in which firms differ in their ability to generate profits, so that there are some firms that are more productive than others. In this article, highly productive firms can signal their type through their dividend policy. One crucial assumption of the model is that new investments can only be financed through the previous period retained earnings and through new equity issues. However, the amount of equity that a firm may issue is limited to the difference between the cost of new investments and the amount of the previous period retained earnings. Therefore, if managers want to distribute dividends, investments must be reduced of the same amount of the payment.

Therefore, this model exhibits a positive relationship between the signal's costs and the firm's ability to generate profits, so that the signal is costlier for more productive firms: these firms would benefit from maintaining their profits into the production process to exploit their superior productivity.

Despite the fact that the signal is costlier for more productive firms, it is still possible to reach an equilibrium, because the benefits that a firm obtains from signaling that it belongs to the highly productive typology are positively related to its future cash flows.

In equilibrium, low productivity firms invest up to their first best level and do not pay dividends, while high productivity firms invests less than their first best level and pay dividends with the spare funds, signaling their type.

The model presented in Miller and Rock (1985) has similar implications to that of Heinkel (1978), but it does not need to impose any restriction on the size of the dividend distribution. In this model, investors can calculate the optimal level of new investments that firms should undertake. This assumption, coupled with the fact that firms employ all their profits and the capital obtained from new equity issues to finance investments and to pay dividends, makes it possible for investors to calculate the current cash flows of a firm as soon as it announces its dividend policy. Since dividend payments are costly for the firm (as they require that some resources are distracted from investments), but this cost is higher for those firms that have low current cash flows, the model predicts that, beyond a certain threshold, they have no incentive to imitate those firms that have high current cash flows. Therefore, in equilibrium, firms with high current cash flows will pay higher dividends than those paid by low current cash flows firms, revealing their type and benefitting from an increase in their share price.

2.2.1 Empirical evidences on dividend signaling

The hypothesis that dividends have some information content has two important implications that have been empirically tested. The first is that changes in the dividend policy should be followed by changes of the same sign in earnings, and the second is that sudden and unexpected changes in dividends should be accompanied by both changes in the market's expectations about future earnings and in share prices of the same sign. Downes and Heinkel (1982) reject the hypothesis on the information content of dividends, while Healy and Palepu (1988) find that significant changes in the dividend policy transmit information about future changes in earnings, and that those changes can be inferred, at least partially, since the announcement. Also Dyl and Weigand (1998), Nissim and Ziv (2001) and Lie (2005) find evidences that support the dividend signaling hypothesis.

If we also consider the presence of taxes, the signaling theory implies that after a firm announces higher dividend payments than expected, its earnings should increase more the higher the taxation level. Evidences that support this prediction are provided by Bernheim and Wantz (1995), while Grullon and Michaely (2002) observe that the market has responded more positively to increases in dividends after 1986, the year in which the taxation on dividends in the US was reduced. Amihud and Murgia (1997) find mixed evidences, as they indeed observe higher earnings in the U.S.A. after unexpected dividend increases, but they are comparable to those reported in Germany, where the taxation level on dividends is lower.

3. G*ame theory*

Despite the fundamental intuition that some management's action may have a relevant information content in settings characterized by information asymmetries, many of the papers examined in the previous paragraphs lacked the rigor and the formal structure that are typical of game theory.

For example, not enough attention is paid nor to who the first mover is and neither to the sequence of the actions that unfolds, taking for granted that the party holding relevant information is the first to act, while the other party acts in response to the signal, trying to interpret it to fill the information gap he has. But what if the first mover is the part that does not have the relevant information?

Moreover, it was not considered the possibility that, during the interaction, the information available to the parties may gradually increase, requiring the update of the agents' initial beliefs.

In the years that followed, these issues were tackled adopting the typical instruments of game theory.

In the following paragraphs we review the essential characteristics and the structure of strategic games, the concept of Nash equilibrium, and then we focus on games with incomplete information and on the concept of PBE (perfect Bayesian equilibrium), which is of particular importance in the finance literature.

3.1 *Definition of games*

Game theory, which owes its name to von Neumann and Morgenstern (1944), analyzes situations in which the result depends on the choices made by two or more players that pursue objectives that may be common or conflicting, both in certain and uncertain settings.

However, this alone is not sufficient to describe what a typical situation analyzed in game theory is: players need to act strategically, taking into account both the actions of the other players and the consequences that their own actions have on them. Consequently, the most important assumption of game theory is that players need to be rational.

An individual is considered rational if he has definite preferences over the set of possible outcomes, and if he implements the best possible strategy to obtain them. This assumption implies that players are aware of the strategies at their disposal and at the disposal of the other players, and that they are able to determine the best strategy and follow it.

A game, therefore, is the description of the strategic interactions between multiple players, which considers both the actions the players can take and the restrictions they are subject to, although it does not prescribe which actions are actually taken. Then, the solution of a game is the description of the possible results.

Different types of games exist. It is possible to distinguish between static and dynamic games, between games with complete or incomplete information, cooperative or non-cooperative. A game is static if the players move only once and simultaneously, while it is dynamic if players can act more than once. It is said to have complete information if players know all the actions and the outcomes of other players, while it is said to have incomplete information even if only one player lacks this information.

Finally, a cooperative game is characterized by the fact that the players' interests do not conflict, but there is a common interest, so that some of them may group together to improve their pay-offs. In non-cooperative games, also known as competitive games, players cannot act this way, regardless of their objectives. The famous solution concept developed by Nash (1950) can be applied to this category.

A game is usually described in its extensive form, which specifies who is the first mover, the information and actions available to each player, the pay-offs of each player given the action of all the others and, in some cases, a probability distribution.

If a player chooses its actions with certainty then he is playing in pure strategies. Instead, if the player chooses randomly among the available actions on the basis of a probability distribution, then he is playing in mixed strategies. The pay-off of a mixed strategy is the expected value computed using the pay-offs of the pure strategies that it consists of.

3.2 *Nash Equilibrium and Subgame Perfect Equilibium*

The most commonly used solution in game theory is the so-called Nash equilibrium. A Nash equilibrium is reached if, although every player knows the equilibrium strategies of the others, none has an incentive to deviate from their own.

A more formal definition is the following:

Definition:

A Nash equilibrium <N, (A_i), $(\succsim_i)$> is a *profile* of actions $a^* \in A$, characterized by the fact that, for every player $i \in$ N, it is:

$(a^*_{-i}, a^*_i) \succsim_i (a^*_{-i}, a_i)$ for all $a_i \in A_i$.

In this definition, N is the set of players, A is the set of actions, and $\succsim$ is a preference relation over the set A. The above formulation has the following meaning: if the other players play their equilibrium strategies, in a Nash equilibrium a player have at his disposal no better strategy than the equilibrium one. Therefore, once the equilibrium is reached, no player has an incentive to depart from it.

This type of solution, in addition to pure strategies, may also be applied to mixed strategies, considering expected pay-offs instead of certain ones.

The concept of Nash equilibrium is not suitable for dynamic games, where a player performs his actions *after* observing the actions of other players, which cannot be considered as given anymore.

The sub-game perfect Nash equilibrium is an improvement of the original concept. It consists of the set of strategies that constitute a Nash equilibrium for each of the sub-game of the original game.

This type of solution is usually obtained through a procedure known as backward induction, which consists in starting the analysis from the final mover, trying to determine the actions that maximize his utility in every possible node in which he may end up playing. Then, the next step is to analyze the actions of the second to last mover, identifying those that maximize its utility. This procedure continues until the optimal actions of the first mover are determined. The strategies that survive this process constitute the set of all subgame perfect equilibria.

3.3 *Bayesian Games*

As already discussed in the previous paragraphs, the concept of information asymmetry has assumed a particular importance in the financial literature starting from the late '70s. In order for a situation characterized by information asymmetry to be properly represented using game theory tools, the fact that players do not have complete information about other players (in terms of strategies and / or payoffs) need to be taken into account. This is what happens in games with incomplete information, where players have initial beliefs about the type the other players belong to (there is a probability distribution over the possible types of players), and they can update them using Bayes' rule during the course of the game, as soon as new information is available after that some player has acted. Therefore, a bayesian Nash equilibrium is a set of strategies such that every player maximizes his expected utility once considered the strategies adopted by rest of the players.

More specifically, in equilibrium a player knows the strategy adopted by the other *types* of players. However, he does not know to which *type* the other players belong to, therefore he chooses a strategy that allows him to maximize the expected value of his pay-offs.

This solution concept provides, for dynamic games, an excessively high number of equilibria. Better results can be obtained through the application of another solution concept, the Perfect Bayesian Equilibrium. It consists of a set of *sequentially* rational strategies given the players' beliefs, which must be consistent with the actions taken by the other players in the various stages of the game.

4. *Game theory* in the Finance literature

In this paragraph we review some of the most important applications of game theory to three relevant topics in the field of the financial literature. We examine, as done for the signaling theory, the capital structure issue and the “dividend puzzle”. Moreover, we also analyze the major contributions within the field of financial intermediation, for which the application a of game theory has been particularly prolific.

4.1 Capital Structure

Noe (1988) studies whether the pecking order theory is consistent with the formal structure of a sequential signaling game. He manages to show that, if managers have perfect information about their firms’ cash flows while the market ignore it, it is possible to reach a sequential equilibrium in which the pecking order theory is violated, although the debt’s positive signaling role still holds.

To achieve this result, he develops a game in which there are three types of firms, which differ among them for the amount of their cash flows. They have the opportunity to invest in a project with a positive NPV, and need to choose the most appropriate financing source. In equilibrium, all firms invest in the project, but the two types that have the lowest and the higher amount of cash flows respectively decide to finance their investment with debt, while the other type (that, in Noe’s example, is also the most numerous, consisting in 99.1% of all firm, whereas the other two types, amount to 0.1% and 0.8% respectively) finances its investment with equity.

This equilibrium can be reached because of the reasoning that follows. Firms with low cash flows have an incentive to imitate those firms that have high cash flows rather than those with average cash flows, since their equity would be priced more or they would benefit from a lower interest rate.

However, firms with average cash flows do not want to be confused with firms that have low cash flows, as the cost that they would suffer from being mistaken as one of them is higher than the benefit they would obtain from being mistaken with high cash flows firms.

If a high cash flows firm were mistaken for another type, both its debt and equity would be underpriced. Therefore, high cash flows firms prefer to finance their investment with debt, since it is less sensitive to this problem. Thus, firms with low cash flows will also choose to issue debt, while firms with average cash flows will issue equity, violating the pecking order theory.

The market is able to correctly identify firms with average cash flows applying Bayes' rule, and realize that the rests of the firms belong for 8/9 to the type with high cash flows, and for 1/9 to the type with low cash flows. Since new debt issues are for the most part done by the former type, debt keeps its positive signaling role. However, this result depends on the initial distribution.

A recent application of the game theory approach in this area of the finance literature is Morellec and Schürhoff (2011). In their paper, the authors develop a dynamic model in which managers have private information about the potential growth of their firm. In this model, the firm needs to raise capital to invest in a risky project. For this purpose, it can both choose how to finance it and the timing of the investment.

The authors show, assuming that investors are rational and that they use Bayes' rule to update their beliefs, that firms may use the timing of the investment and their leverage to signal their type to investors. The investment timing may be chosen as to be more costly for low quality firms (i.e. anticipating it with respect to the optimal timing), thus providing one of the typical conditions of *signaling theory* and discouraging them from mimicking the actions of good quality firms, allowing for a separating equilibrium to be reached. Thanks to these signals, they also show that the presence of information asymmetries does not necessarily translate into the existence of a pecking order among the sources of capital.

4.2 Dividend Policy

Also the *dividend puzzle* was analyzed with the tools provided by game theory. Kumar (1988) begins his analysis assuming that dividends may indeed signal the future earnings of a firm, but the signal is “coarse” and, therefore, dividends’ signaling power is not strong enough to fill the existing information gap alone. Kumar builds a two-period model with two players, the manager / entrepreneur and one representative shareholder. Both of them are risk-averse and try to maximize their own utility. He assumes that the firm’s productivity depends on the manager’s, which is only known to him. The manager/entrepreneur can also choose the investment and the dividend policies of the firm.

This model allows for the presence of sequential equilibria in which firms smooth their dividends: firms that belong to a certain productivity range all pay the same amount of dividends. Only when a firm leaves its range it changes the amount of dividends paid. As a result, the signaling value of dividends turns out to be weaker than predicted by signaling theory: dividends are not suitable predictors of future earnings, because they can only signal them coarsely.

Williams (1988) presents a model in which it is possible to obtain an efficient signaling equilibrium for a continuum of firms that possess information about the performance of their non-financial investments that outsiders do not have. The novelty of this model is that it takes into account the possible existence of multiple signals: firms may pay dividends, invest in real and financial assets, and issue new shares.

In the model, the representative firm operates for a single period, and then it is liquidated. It can only finance their investments with internal funds, which correspond to the initial endowment, or by issuing new shares. The manager's aim is to maximize the welfare of its shareholders.

In equilibrium, each firm invests in order to maximize its value. To finance their investment, firms both use their internal funds and raise capital by issuing new shares, and use dividends to signal their value to keep high the value of their shares. The amount of dividends paid is greater the greater the return on investments in non-financial assets, known only to the manager: therefore, according to Williams, dividends have a relevant information content.

4.3 Financial Intermediation

A field of application that has been quite fertile for game theory in the financial literature is *intermediation*. This was to be expected, since the presence of information asymmetry is the main reason that justifies the existence of financial intermediaries.

Stiglitz and Weiss (1981) is the main contribution to the theory of credit rationing. The authors show that the loan market can be in equilibrium even though demand is only partially satisfied. This phenomenon is known as *credit rationing.* In this model, lenders (banks) use different *tools* to distinguish between good and bad borrowers. The most important of these tools is the interest rate because, in the presence of adverse selection, it does not only affect demand, but also the borrowers' behavior. In fact, similarly to what happens in Akerlof's *market for lemons*, an excessively high interest rate causes good potential borrowers (which invest in safe but only moderately profitable projects) to give up on the loan. However, this interest rate will be accepted by borrowers that plan to invest in risky projects, which can have very high pay-offs but, at the same time, are characterized by a high probability of failure: these type of borrowers are willing to borrow at high rates because they will repay the loan only if they “score big”, otherwise they can simply default on the loan and walk away. Moreover, as the interest rate increases, borrowers will begin to undertake projects with higher chances of failure. Because of these reasons, the lenders’ expected return may increase less quickly than the interest rate, and beyond a certain point it may also decrease. Therefore, at the interest rate that maximizes the lenders’ return there may be excess demand caused by credit rationing.

Another famous contribution in the field of financial intermediation is Diamond (1989), which analyzes the role carried out by reputation in the relations between lenders and borrowers.

Diamond develops a repeated game in which there are two types of players: lenders receive an endowment in each period, while borrowers have access, once per period, to one or two investment projects, depending on their type. There are three types of borrowers: those who have access to a risk-free project; those who have access to a risky project with a low expected return, but which, if successful, has a higher pay-off than the safe one, and a pay-off equal to zero in case of failure; and those that, in each period, may choose between one of the two projects.

Both the borrower's type and return of the investment are private information. Since lenders cannot distinguish the borrowers' type, the initial lending rate simply reflects their beliefs. In this situation, those borrowers that can choose between the two projects maximize their pay-off by choosing the risky one. If their bet is successful, they get a positive high pay-off and avoid default. Lenders observe whether borrowers default or succeed, update their beliefs accordingly, trying to figure out the likelihood that a borrower has at his disposal only safe projects, and changes the lending rate. After a number of repetitions in which they manage to avoid default, those borrowers that can choose between the two projects will only invest into the safe one, not to ruin their track record that allows them to have an advantageous borrowing rate. Diamond argues that this moment will come sooner the lower is the degree of adverse selection.

The equilibrium concept used in this game is the *sequential Nash equilibrium*, defined in Kreps and Wilson (1982b), which requires that at each stage of the game, and for all possible actions, lenders have some beliefs about the borrowers' type, and that their actions are the best once considered such beliefs.

The last paper we review is Hart and Moore (1998), which develops a two-period model in which there are an entrepreneur that needs funds to finance a project, and an investor. They have the same information, however third parties (e.g., court) do not have access to most of it, therefore it is not possible to enforce any written contract. The entrepreneur, therefore, may decide to seize all the investment's return and default. However, in this case the investor is entitled to liquidate all the project's assets. Should this happen, the two parties can renegotiate the contract and starting anew. The focus of the analysis of the authors is the problem of providing incentives so that the entrepreneur decides to repay his debt. Hart and Moore analyze different contract types, and derive sufficient conditions for the debt contract (together with the investor's right to liquidate the borrower's asset) to be optimal.

Conclusions

Since its first formulation in Spence (1973), *signaling theory* has been applied to a large number of different fields to explain agents' behaviour in situations characterized by information asymmetry.

In the corporate finance literature it has been used to find a connection between the dominant economic theory at that time (Modigliani and Miller, 1958; Miller and Modigliani 1961), and what could be empirically observed.

In this review we have focused on three different typologies of *signals*: the amount of debt held, new equity issues, and dividend distributions.

There are not unequivocal evidences that support the idea that these signals have an autonomous information content: the evidences about a relationship between debt and firm value are mixed, but there is consensus on the negative information content of new equity issues. It appears that also dividend distributions have an information content, since it has been found empirically that the announcement of higher dividends than the those that the market expects is correlated with an increase in future earnings: however, it also appears that the effectiveness of this *signal* is independent from its cost (that mainly depends on the taxation level), although the theory predicts otherwise.

We also reviewed some of the most significant contributions to the financial literature that apply game theory. This approach was introduced to further develop and study the role of information economics in the literature, initially imported by signaling theory, using, however, a more structured and rigorous analysis. In particular, we focused on three major areas, which are capital structure, dividend policy, and financial intermediation.

Before concluding, we want to suggest a possible field of application for the *signaling theory* that still does not appear to have been researched extensively. We refer to the possibility that managers may convey information about their firm's value through the amount of cash holdings.

When the signaling theory was firstly introduced and knew its maximum diffusion, only little attention was paid to cash, since it was considered to be only loosely (or none at all) related to firm value. This situation lasted until the nineties, when the liquidity held by firms started to steeply increase.

From recent studies, cash holdings appear to be particularly important for those firms that invest considerably in R&D, since they are more exposed to asymmetric information problems. As a consequence, they have more difficulties in raising capital. Significant amount of cash holdings allow those firms to continue investing in their R&D projects, that usually consist of long-term investments and that need stable financial flows, even if external funds are scarce and/or excessively expensive (Harford et al. 2008; Gao et al, 2013; Pinkowitz et al., 2013).

Therefore, for R&D intensive firms the simple presence of high levels of cash holdings may act as a signal for the market, which could infer from it that the management is confident in its ability to find and exploit profitable investment opportunities, especially if they are related to R&D projects. This signal may be strong enough to reduce information asymmetry, at least partially. However, this relationship between cash holdings and information asymmetries does not appear to be convincing for non financially constrained firms, where large amount of cash holdings may have no significance as a signal, or possibly simply reveal a lack of opportunities.

The positive effect of cash holdings' signaling role may exceed, at least for R&D intensive firms, the negative effect that has been traditionally associated to them, as they have been indicated as the cause of underinvestment or of agency problems (Jensen, 1986). High levels of cash holdings may help reducing information asymmetries, with important effects on the costs and availability of the other source of capital, which would benefit from this reduction.

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Chapter 2

Cash holdings and Information Asymmetry in U.S. R&D Intensive Firms

Abstract

In this paper we investigate the relationship between corporate cash holdings and information asymmetry in R&D intensive firms. Using a partial adjustment model of firm performance, we empirically test two hypotheses. According to the recent literature, corporate cash holdings have an important role in R&D intensive firms. We hypothesize that cash holdings act as a signal of firm performance, and may decrease the degree of information asymmetry that affects the firm. We also expect the optimal amount of cash holdings for R&D intensive firms to be higher than that of non R&D intensive firms. The partial adjustment model is designed so that the adjustment speed parameter is a proxy for the degree of information asymmetry. Our results support both hypotheses, and we also show that cash holdings have no relationship with information asymmetry in non R&D intensive firms.

Introduction

U.S. firms cash holdings have been growing continuously since the early 2000s, reaching peaks considered inconceivable only a few decades ago. As a result, the attention to cash holdings increased, and many authors studied this phenomenon in order to identify it causes.

Until then, cash holdings had been neglected for a long time. The main reason was that corporate finance theory was based on the hypothesis of perfect capital market: as a corollary, cash holdings were irrelevant and all sources of capital had the same cost. If this hypothesis is removed, firms need to carefully consider all sources of capital (that now have different costs) and optimize their choices. In this setting, also cash holdings become important, because managers may be forced to pass on profitable investment opportunities if external sources of capital are too expensive, and there are not sufficient internally generated funds.

The literature has studied different market imperfections (e.g. transaction costs, agency problems, etc.). In this paper we focus on information asymmetries, and study the relationship between them and cash holdings. This relationship has already been explored, at least partially, by Drobetz et al. (2010). However, the authors focus on the ***value*** of cash and finds that increasing information asymmetries can reduce it, supporting Jensen (1986)'s free cash flow hypothesis.

In this article the perspective is reversed: we are interested in the effect that cash holdings may have on information asymmetries, and in particular if they can be a valid signal of firm performance and, should this be the case, if the signal is strong enough to reduce information asymmetry. Moreover, we focus on R&D intensive firms, which are structurally more exposed to the asymmetric information problem.

The idea behind this hypothesis is the following: cash holdings are especially important for firms that are financially constrained (Denis and Sibilkov, 2010) as, for example, firms that are small or were recently founded, or that operate in R&D intensive industries (Brown and Petersen, 2011), where information asymmetries are more relevant (Holstrom, 1989); since financially constrained firms tend to underinvest (Myers and Majluf, 1984), large amounts of cash holdings may be a strong signal of a firm's aptitude to produce profits. Even more, since holding cash is costly, they may signal that the management is confident in its ability to find and exploit profitable investment opportunities, especially if they are related to R&D projects.

The idea that cash holdings may be a signal for firm performance is consistent with Martinez-Sola et al. (2013): they find evidences that cash holdings and firm value have an inverse U-shaped relationship that allows for a maximum; therefore, up to a certain value, increases in cash holdings are related to increases in firm value. If cash holdings have some signaling power, it may be strong enough to reduce information asymmetry, at least partially. However, this relationship between cash holdings and information asymmetries does not appear to be convincing for non financially constrained firms, where large amount of cash holdings may have no significance as a signal, or possibly reveal a lack of opportunities.

Following this reasoning, we test the hypothesis that cash holdings may help reducing information asymmetries in R&D intensive firms. We estimate a partial adjustment model of firm performance, and use the *adjustment speed parameter* as a measure of information asymmetry.

Our results support this first hypothesis, showing that there is an inverse relationship between cash holdings and information asymmetry in R&D

intensive firms. This result does not seem to be a case of reverse causality, since we also obtain that this relationship is absent in non R&D intensive firms (if we were confusing cause and effect, than we should have found the same relationship also in non R&D intensive firms).

To our knowledge, this hypothesis is new in the corporate finance literature, and highlights the strategic role of cash holdings, role that has already been studied and recognized by the Strategic Management Literature (O'Brien, 2003; O'Brien and Folta, 2009).

This result, together with the other arguments that the literature provides and that support the importance of cash holdings for R&D intensive firms (Brown et al. 2009; Brown et al. 20012), is at the basis of our second hypothesis, that is that the optimal amount of cash holdings in R&D intensive firms is higher than in non R&D intensive firms. Our results show that an optimum level of cash holdings exists, and that it is higher for R&D. Therefore, this paper contributes to that research stream that focus on the importance and the role that cash holdings have in R&D intensive firms (Himmelberg and Petersen, 1994; Hall, 2002).

The paper is structured as follows: **Section 1** presents the theoretical background and our hypotheses; **Section 2** explains the empirical model; **Section 3** describes data and variables; **Section 4** reports our empirical results; **Conclusions** follow.

1. Motivation

Theoretical Background and Hypotheses

Managers need to carefully consider the existence of information asymmetries between outsiders and insiders, since it has severe implications for capital structure and internal funds related decisions. For example, the pecking order theory suggested by Myers (1984) and Myers and Majluf (1984) predicts that if there are significant information asymmetries, managers should prefer debt financing to equity financing, since it should be less expensive. This argument has been validated both theoretically and empirically, with major studies that link information asymmetries to high equity costs (Dierkens, 1991; He et al., 2013) and to high leverage levels (Bharath et al., 2009; Gao and Zhu, 2015).

Information asymmetries may also be negatively related to firm value, as the *undervaluation hypothesis* predicts: if managers have more information about future firm performance than the market has, they might determine the value of the firm more precisely (Grullon & Michaely, 2004); therefore, they could take advantage of this situation, and issue new shares when the firm is overvalued (or repurchase them when the firms is undervalued). Rational investor will expect this behaviour, and will lower their valuation of the new shares, which leads to a wealth transfer from old to new shareholders. As a consequence of the undervaluation, old shareholders may decide not to invest into some profitable projects, causing underinvestment.

Hence, high degrees of information asymmetries cause serious difficulties for the firm, which may try to reduce them through reporting or voluntary disclosure of private information (see Healy and Palepu, 2001). Or, as some authors have pointed out, some managers' actions may have a signaling value that is able to fill the existing information gap, as resorting to bank debt financing have, since it conveys positive information to the market because of the monitoring and screening activities performed by banks **(**Krishnaswami et al., 1999**)**.

R&D intensive firms cannot easily resort to any of the above mentioned relieves to information asymmetries: disclosing private information is risky, since competitors may readily imitate innovations (Hall, 2002), and debt financing has only a marginal role. At the same time, R&D intensive firms suffer from comparatively more severe information asymmetries, because the inventor has more information about the probability of success and future payoffs of an R&D project than outsiders have. Therefore, innovation financing resembles closely the market for "Lemons" modelled by Akerlof (1970). As a consequence, investors find difficulties in determining the correct value of and R&D intensive firm (Brown et al., 2012; Brown et al., 2009; Brown and Petersen, 2009).

For this type of firms, cash holdings may act as a signal of firm performance to the market, and may be able to reduce information asymmetries, at least partially. Indeed, the literature has already pointed out that cash holdings are a key element for the financing decisions of R&D intensive firms: since R&D expenses consist largely in wages, they need a steady flow of resources, and high amounts of cash holdings allow a firm to continue its investments in innovation even if external funds are scarce and/or excessively expensive (Harford et al. 2008; Gao et al, 2013; Pinkowitz et al., 2013). Therefore, the market may positively value the simple presence of substantial cash holdings in R&D intensive firms, with important implications for the availability and cost of equity, although the literature has addressed large amount of cash as the cause of underinvestment and the source of agency problems (see Jensen, 1986).

Given the aforementioned considerations, we propose our first hypothesis:

Hypothesis 1: There is an inverse relationship between cash holdings and information asymmetries in R&D intensive firms. This relationship is absent, or comparatively less important, in non R&D intensive firms.

This hypothesis is based on the idea that cash holdings may be a signal for firm value. If the information content of cash holdings is strong enough, then it may fill the information gap that exists between managers and investors, at least partially, thus reducing information asymmetry.

This reasoning is consistent with Martinez-Sola et al. (2013) and La Rocca and Cambrea (2016). Martinez-Sola et al. find that cash holdings and firm value have an inverse U-shaped relationship; therefore, up to a certain value, increases in cash holdings are related to increases in firm value, suggesting the idea that cash holdings may actually have some signaling power about firm performance. La Rocca and Cambrea, in their recent working paper, suggest that there is not a clear consensus on the idea that cash holdings and firm value are related because, depending on some internal and external factor, as the industry in which they operate, this relationship may be negated.

hey finds that the positive effects of cash holdings on firm performance is particularly strong in financial constrained firms, as it is the case for R&D intensive firms.

In our analysis we also employ debt as a determinant of firm performance. Debt may also have and information content similar to that that we hypothesize for cash holdings, but we did not explore this possibility because of the characteristic of R&D intensive firms: since they usually lack the collateral required by financing institutions (for the most part, R&D expenses consist of wages for researchers and highly skilled workers (Brown and Petersen, 2009; Brown et al., 2012), debt financing has only a marginal role in R&D intensive firms.

Even though the increasing interest for information asymmetries in the corporate finance research (e.g. Shen, 2014; Drobetz et al., 2010; Lu et al., 2010; Agarwal and O'Hara, 2007), to our knowledge, this hypothesis is new in the literature. The importance of cash holdings in R&D intensive firms is not a novelty but, should our first hypothesis be confirmed, cash holdings may actually be more important than previously believed. Also their strategic role, which has been studied by strategic management scholars, may be deeper than already recognized. (O'Brien e Folta, 2009).

Therefore, it is reasonable to expect R&D intensive firms to hold more cash than non R&D intensive firms. Indeed, Opler et al. (1999) found that small, but highly innovative firms with unstable cash flows hold comparatively more cash. However, we still do not know whether holding more cash is an optimal behaviour with respect to firm performance. This leads to our second hypothesis:

Hypothesis 2: The optimal level of cash holdings is higher in R&D intensive firms.

2. Empirical Methodology

To test our first hypothesis, we need a model that is able to capture the degree of information asymmetry that affects the firms in our sample. We choose to employ a partial adjustment model of firm performance. This model allows to measure how quickly the market can correctly evaluate the effects that new strategies and investments have on firm performance. The idea is that insiders have a target level of firm performance that they plan to reach when investing and implementing new strategies, but the market neither knows this target level, nor it has all the relevant information to predict how will firm performance change, therefore it need time to adjust his valuation. A partial adjustment model is able to take into account this process. We choose firm performance as the independent variable of our model because of its relationship with cash holdings, i.e., that cash holdings may be one of its determinants: we estimate the coefficient of the interaction between cash holdings and the speed of adjustment to test whether cash holdings may reduce the level of information asymmetry.

The *target equation* is the first building block of a partial adjustment model: it is the mathematical representation of the relationship between the "target" level of the dependent variable that managers intend to reach, and the independent variables that determine it.

The basic formulation of a *target equation* is expressed by **Equation (1)**:

$$q^*_{i,t} = \boldsymbol{\beta}\, \boldsymbol{X}_{i,t} \,, \qquad \textbf{(1)}$$

where $\boldsymbol{X}_{i,t}$ is a vector of covariates and $\boldsymbol{\beta}$ is a vector of coefficients.

In this paper, $q^*_{i,t}$ represent the target firm performance that managers intend to reach through the adoption of different strategies and the implementation of new investments. Therefore, the covariates we use in our analysis need to be plausible determinants of the target firm performance.

However, the market is not able to immediately determine the effect of new strategies and investments on firm performance because of the limited amount of information it possesses. Therefore, to correctly model the market's evaluation process of firm performance we need a new equation that considers the limited amount of information available to the market and the time it needs to correctly evaluate firm performance:

$$q_{i,t} - q_{i,t-1} = \lambda(q^*_{i,t} - q_{i,t-1}) + \varepsilon_{i,t} \qquad \textbf{(2)}$$

Equation (2) is able to capture the dynamics of the market's evaluation process. The market's evaluation of firm performance is represented by $q_{i,t}$, and it can be observed. The parameter λ is called *adjustment speed parameter,* and represents the speed of convergence of $q_{i,t}$ (the market's evaluation of firm performance) to $q^*_{i,t}$ (the target firm performance that managers plan to reach): if it takes value 1, then the market can *immediately* determine the "new" firm performance after the implementation of new strategies and investments, and this coincide with a situation in which the market has all the relevant information it needs; if λ takes value 0, then there is no convergence between $q_{i,t}$ and $q^*_{i,t}$, because the market has no information that it can use to evaluate firm performance. Both cases are not realistic, therefore we expect λ to take values between 0 and 1.

In our setting, the parameter λ states how precisely the market can evaluate firm performance. Therefore, it can be seen as a measure of the degree of information asymmetries: should the market have all the available information, it could perfectly evaluate firm performance, and λ would take value 1. Conversely, should the market have no information about the firm, λ would take value 0 and the market would not be able to evaluate firm performance.

By substituting **Equation (1)** into **Equation (2)**, we obtain the partial adjustment model:

$$q_{i,t} = (\lambda\boldsymbol{\beta})\boldsymbol{X_{i,t}} + (1-\lambda)q_{i,t-1} + \varepsilon_{i,t} \qquad \textbf{(3)}$$

3. Data and variables

Our sample is an unbalanced panel of U.S. public firm extracted from the Compustat database. It consists of all the observations reported over the period 1989 – 2013.

We started with 281.870 observations, then we dropped those that refers to financial firms (SIC 6000 to 6999), to regulated utilities (SIC 4000 to 4999), and to miscellaneous services not elsewhere classified (SIC 8999). After this process, observations were reduced to 181.380.

We also dropped those observations that report values of *total assets* (item 6) and *sales* (item 12) less than $ 1 million, or that miss the information, and those observations that report negative *cashflows* (income before extraordinary items (item 18) + depreciation and amortization (item 14) to the lagged value of property, plant, and equipment total investment (item 8)).

Lastly, we dropped those observations that report a growth rate of sales greater than 100%, so to reduce outliers caused by mergers and acquisitions, ending up with 44.329 observations. It is worth noting that the 1989 observations are not actually used for the partial adjustment model estimation since the model includes the first lag of the dependent variable.

The dependent variable of our model is firm performance; since it cannot be observed, we use the tobin's q as a proxy. The tobin's q has the nice feature of incorporating expectations about future performance and growth opportunities, and it is not dragged down by huge investment in R&D as it happens with other accounting measures. Following Gompers et al. (2003), we compute the tobin's q as the market value of assets divided by the book value of total assets (market-to-book, *mtb* in our analysis). More precisely, *mtb* is equal to the book value of total assets (item 6), plus the market value of equity (item 199, price-close × item 54, shares outstanding), minus the book value of common equity (item 60), and minus deferred taxes (item 35), everything divided by total assets (item 6).

Given the formulation of the *target equation* expressed by **Equation (1)**, the independent variables that we use in our empirical model need to be plausible determinants of the *target firm performance*. To make them comparable to *mtb*, all the variables in our study are scaled by total assets (item 6); moreover, all variables are winsorized at the 1^{st} and 99^{th} percentile.

Cash is the most important independent variable in our analysis, and it has already been linked to firm performance (O'Brien and Folta, 2009); it measures a firm's cash holdings, and it is computed as cash (item 162) to total assets (item 6). The variable *debt* is computed as liabilities (item 181) to total assets (item 6); since it is scaled to total assets, this variable actually measures the firm's leverage; together with *cash*, it can measure the *financial slack* of the firm. Indeed, having spare debt capacity may hold similar benefits of having sizeable cash holdings: however, the reason cash holdings are the object of interest of our analysis rather than *financial slack* is that debt is of limited importance for R&D intensive firms. The variable *rd* is computed as research and development Expense (item 46) to the lagged value of total assets (item 6), and measure the intensity of R&D investment. In addition to entering the *target equation*, the variable *rd* is used to split the sample into R&D intensive and non R&D intensive firms, a necessary step to test *Hypothesis 2*. The variable *investment* is capital expenditure (item 128) to the lagged value of total assets (item 6); it enters the *target equation* as a plausible determinant of the target firm performance.

The last variable that enters the *target equation* is *profitability*, computed as income before depreciation (item 13) to total assets (item 6). It cannot be considered as a direct determinant of the target firm performance, since managers cannot simply change it according to their plans; however, we need it to better estimate the indirect effect that the other regressors may have on target firm performance through their direct effect on the firm's profitability.

All the variables that we have discussed enter the *target equation* additively. This is a major limitation of our paper, since it would be better to develop a theoretical model of target firm performance and use it as the partial adjustment model's *target equation*.

In this paper we employ two different specifications of the *target equation*: we use the first, expressed by **Equation (4)**, to test *Hypothesis 1*, and the second, expressed by **Equation (5)**, to test *Hypothesis 2*. They differ because of the variable $cash^2$ that appears only in the second specification.

$$mtb_t = \beta_0 + \beta_1 rd_t + \beta_2 cash_t + \beta_3 debt_t + \beta_4 debt_t^2 + \beta_5 investment_t + \\ + \beta_6 investment_t^2 + \beta_7 profit_t + \varepsilon_t \qquad \textbf{(4)}$$

$$mtb_t = \beta_0 + \beta_1 rd_t + \beta_2 cash_t + \beta_3 cash_t^2 + \beta_4 debt_t + \beta_5 debt_t^2 + \\ + \beta_6 investment_t + \beta_7 investment_t^2 + \beta_8 profit_t + \varepsilon_t \qquad \textbf{(5)}$$

The reason why we need two different specifications is that to test *Hypothesis 1* we need to let interact the variable *cash* with the first lag of *mtb*, since we want to verify whether *cash* may reduce the degree of information asymmetries; should we let $cash^2$ enter the partial adjustment model, it would be difficult to interpret the meaning of the interaction. On the contrary, to test *Hypothesis 2* we need *cash*^{2} to enter the *target equation*, because a non linear relationship between *cash* and *mtb* is a necessary condition for an optimal value of cash to exist.

Table 2.1 reports descriptive statistics for our variables of interest.

4. Results

4.1 Regression of the target equation

As we explained in the previous paragraph, the variables of interest of this study that enter the *target equation* and the partial adjustment model need to be plausible determinants of the target firm performance. Therefore, the first step of our analysis consists in regressing **Equation (4)** and **(5)**, the two specifications of the *target equation*, because we need to test the significance of the regressors, as to infer whether they are a suitable choice for determinants. Since there are no observations about the target firm performance chosen by managers, the best course of action is to use the **observed** *mtb* as the dependent variable.

Our dataset contains multiple observations for each firm; therefore, firm-level effects may cause unobserved heterogeneity. We perform the estimation using the *fixed-effect estimator robust to heteroskedasticity,* favouring it over the random-effect estimator for the following reasons: our sample does not consist of a random draw from the population (which is the usual case where the random-effect estimator performs better than the fixed-effect estimator), but of the entire population; the estimations performed with the random-effect estimator are highly susceptible to biases that result from failing to include in the model all the explanatory variables that influence the dependent variable (Allison, 1994); lastly, the Hausman test we performed indicates that there is a significant difference ($p<0.001$) between the coefficients estimated with the fixed-effect estimator and those estimated with the random-effect estimator (since a fixed-effect model is less efficient than a random-effect model, but it is consistent, if the coefficients differs is better to perform the estimation with the fixed-effect estimator).

Table 2.2 reports the estimation results of the two specifications of the *target equation.*

We can observe that all the regressors are highly significant. This indicates that that they are at least plausible determinants of the target firm performance. **Column 1** reports the estimation results of **Equation (4)**, and **Column 2** reports the estimation results of **Equation (5)**. The dependent variable in both specifications is *mtb*.

The positive coefficient of the variable *rd* was expected, since the *market-to-book* includes the expectations about future opportunities and performance. A similar reasoning may be applied to the variable *investment*, even though it is interesting to note that the relationship between *investment* and *mtb* is not linear, since also the coefficient of *investment*^{2} is significant. Moreover, since the coefficient of *investment* is positive, while the coefficient of *investment*^{2} is negative, a firm should have an optimal value of the variable *investment*, beyond which additional investments may reduce firm performance. Also the variable *cash* has a non linear relationship with *mtb*, and since the coefficient of *cash* is positive while the coefficient of *cash*^{2} is negative, target firm performance should have a maximum value in *cash*. In **Section 5.3** we re-estimate **Equation (5)** using two different sub-samples to test *Hypothesis 2*. If *cash*^{2} does not enter the target equation then *cash* has a simple linear relationship with *mtb*, as the estimation result of **Equation (5)** show.

Also the variable *debt* has a non linear relationship with *mtb*, so that it should be possible to find a minimum value of target firm performance with respect to *debt*, since its coefficient is negative while that of *debt*^{2} is positive. Unsurprisingly, the coefficient of the last variable of our study, *profitability*, is positive.

Therefore, the variables we have chosen seem to be reasonable determinants of target firm performance, especially considering the high **adjusted R^2** values reported for the two regressions: **0.6978** for the regression of **Equation (4)**, and **0.6987** for the regression of **Equation (5)**.

4.2 The Partial Adjustment Model

Once ensured that the variables that enter the *target equation* are plausible determinants of target firm performance, the next step of our analysis is the estimation of **Equation (3)**, the partial adjustment model.

The estimation of the partial adjustment model is complicated by the first lag of the *market-to-book*: the estimation of its coefficient performed with the fixed-effect estimator is downward biased, as explained in Nickell (1981). The reason is that subtracting from the dependent variable and the regressors their respective means in a context with a large population but a relatively small number of observations for each unit (large N, small T), as it is the case with our panel, causes a correlation between error and regressors.

A typical procedure to address this problem consists in performing the estimation with the Arellano-Bover / Blundell-Bond system generalized method of moments (GMM) estimator (Arellano and Bond, 1991, Arellano and Bover, 1995, Blundell and Bond, 1998). The system GMM estimator produces coefficient estimates that are consistent and efficient also in the presence of endogenous independent variables and fixed effects. The estimator employs a system of two equations: the original level equation and the equation transformed by first differencing the variables in the original equation. The first difference transformation removes fixed effects. The system GMM estimator then uses the lagged values of the differences and levels of endogenous variables as instruments to control for endogeneity (Foster and Szèkely 2008). However, we performed the Arellano-Bond test (1991) for autocorrelation, and we found second order serial correlation in our model's residuals. We performed the estimation using different sets of instruments, but the Arellano-Bond test results did not change significantly. Test results are available on request.

An alternative may be to perform the estimation with the lsdvc estimator (Kiviet, 1995), that estimates precisely the coefficient of the dependent variable's first lag even in the presence of unbalanced panels and second order serial correlation, as showed empirically in Flannery and Hawkins (2013). However, the lsdvc estimator assumes the strict exogeneity of all regressors; if this is not the case, the estimates of the regressors' coefficients are inferior to those obtained with the fixed-effect estimator, even though the estimate of the lagged dependent variable's coefficient are better. However, considering that our partial adjustment model contains the interactions between the variable *rd* and *cash* and the first lag of *mtb*, and since *rd* is potentially endogenous, we decided to perform the estimation using the fixed-effect estimator, that performers comparatively well even in the presence of an unbalanced panel and second order serial correlation (Flannery and Hawkins, 2013).

We estimate the partial adjustment using three different samples, and report the results in **Table 2.3**.

Column 1 reports the estimation results obtained using the entire sample, while **Column 2** and **Column 3** report the results obtained using only the observations about R&D intensive firms and non R&D intensive firms, respectively. We considered that an observation belongs to an R&D intensive firm if the value of the variable *rd* for that observation is higher than median value of *rd*.

There are two interactions in the partial adjustment model we estimate. The first is between *rd* and the fist lag of *mtb*, and it is necessary to ascertain that our model is indeed able to measure the degree of information asymmetry. The second interaction is between *cash* and the firs lag of *mtb*, and it is needed to test *Hypothesis 1*. Since there are interactions in our model, we centered all variables to obtain better estimates. Moreover, we used **Equation (4)** as the target equation of our partial adjustment model because it does not have $cash^2$, so that it is simpler to interpret the meaning and the implications of the interactions.

Starting with **Column 1**, it is possible to note that the regression is highly significant (**Adjust R^2 0.7643**). All regressors are significant, as the two interactions are. The signs of the coefficients are the same of those that we obtained with the estimation of the *target equation*. As expected, the coefficient of the lagged dependent variable is between 0 and 1.

The first element of interest is the coefficient of the interaction between *rd* and the first lag of *mtb*. The reason is that we claimed that our partial adjustment model can capture the degree of information asymmetry through its *adjustment speed parameter*. Therefore, we were expecting our model to measure a higher degree of information asymmetry in R&D intensive firms. The positive sign of the interaction between *rd* and the first lag of *mtb* confirms our expectations. Indeed, recalling **Equation (3)** (the formulation of a partial adjustment model) it is possible to note that the coefficient of the first lag of *mtb* is equal to $(1 - \lambda)$. This means that there is an inverse relationship between the first lag of *mtb* and the *adjustment speed parameter*. The positive sign of the interaction between *rd* and the first lag of *mtb* means that when *rd* increases, the *adjustment speed parameter* decreases; but a decrease of the *adjustment speed parameter* coincides with an increase of the degree of information asymmetry, by construction. Therefore, it appears that our model is able to measure the degree of information asymmetry

The other important element of our analysis is the sign of the interaction between *cash* and the first lag of *mtb*. Since the sign is negative, the first part of *Hypothesis 1* is confirmed. Indeed, the negative sign of the interaction means that when *cash* increases, the *adjustment speed parameter* also increases and, following a similar reasoning to that applied for the interaction between *rd* and the first lag of *mtb*, the degree of information asymmetry decreases. Therefore, cash holdings seem to have a signaling value for the market, and convey information about the actual and future firm performance.

Continuing with our analysis, we observe that the aforementioned relationship between *cash* and information asymmetries only holds for R&D intensive firms: it is only for these firms that the interaction between *cash* and the first lag of *mtb* is significant, as reported in **Column 2**, while it is not significant for non R&D firms, as reported in **Column 3**. This result was expected, since for non R&D intensive firms the asymmetric information problem is comparatively less important, probably because these firms can obtain external fund more easily, so that cash holding do not have neither the same relevance nor that signaling role that they seem to have for R&D intensive firms.

4.3 The optimal level of cash holdings for R&D intensive firm

To test *Hypothesis 2* we need to re-estimate our partial adjustment model, but this time the *target equation* that enters the model is **Equation (5)**, that contains $cash^2$. The addition of $cash^2$ is essential, since a necessary condition to find an optimal value for *cash* is that it has a non linear relationship with firm performance.

Once **Equation (5)** is estimated, it is possible to differentiate it twice with respect to *cash* and look for a maximum in *cash.*

The first derivative of the partial adjustment model with respect to *cash* is:

$$\frac{\partial mtb}{\partial cash} = \beta_2 + 2\beta_3 * cash \qquad \textbf{(6)}$$

Making this derivative equal to 0, and solving **(6)** with respect to *cash*, we obtain:

$$cash = -\frac{\beta_2}{2\beta_3} \qquad \textbf{(7)}$$

The second derivative of the partial adjustment model with respect to *cash* is:

$$\frac{\partial^2 mtb}{\partial^2 cash} = 2\beta_3 \qquad \textbf{(8)}$$

In order for an optimal value of *cash* to exist, we need both β_2 and β_3 (the coefficients of *cash* and *cash*^{2}*)* to be significant. Moreover, β_3 needs to be negative for the partial adjustment model of firm performance to have a maximum in *cash,* and β_2 has to be positive for this maximum to be in correspondence of a positive value of the variable *cash.*

To confirm *Hypothesis 2* we not only need to verify that an optimal amount of cash holdings exists, but also that this optimal amount is higher in R&D intensive firms. Therefore, we estimate our model two times, once using only those observations about R&D intensive firms, and once using those observations about non R&D intensive firms.

Results of the estimations are reported in **Table 2.4**.

Both regressions are highly significant, as the **Adjusted R^2** indicate (**0.7152** for R&D intensive firms and **0.7843** for non R&D intensive firms). However, only when estimating the model using the observations of R&D intensive firms all regressors are significant. Above all, we can observe that *rd* is not significant for non R&D intensive firms, but this was to be expected given how we separated R&D intensive firms from non R&D intensive firms.

The coefficients of *cash* and $cash^2$ are significant in both estimations, and have the expected signs. Therefore, it is possible and meaningful to compute the optimal value of the variable *cash* both in R&D intensive and in non R&D intensive firms. Using **(7)**, the optimum value of *cash* in R&D intensive firms is equal to **0.427**, while the optimal value in non R&D intensive firms is equal to **0.389**, resulting in a **9.7%** difference.

Conclusions

In this paper we analyzed and tested two different hypotheses: the first predicts that cash holdings can be an effective signal about the performance of R&D intensive firms, and that they may reduce the information gap between managers and market; the second hypothesis predicts that, even in consideration of the first, that firms have an optimum amount of cash holdings, and that the optimum amount of cash holdings is grater in R&D intensive firms.

To test our hypotheses we used a partial adjustment model of firm performance, and we measured the degree of information asymmetry through the *adjustment speed parameter*. We focused on R&D intensive firms, since they are more affected by the asymmetric information problem.

Our results provide evidences that increasing amounts of cash holdings are related to decreasing information asymmetry in R&D intensive firms, while we did not found proof of the existence of this relationship in non R&D intensive firms. However, more research and different approaches are needed to confirm this result.

We also provide evidences for our second hypothesis, finding that the optimal amount of cash holdings is **9.7%** higher in R&D intensive firms. This result is consistent with the relevant literature, which considers cash holdings particularly important for financially constrained firms.

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Appendix

Table 2.1. Descriptive Statistics and correlation coefficients

		Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)
(1)	Market: book	1.515	1.095	0.406	6.713					
(2)	R&D	0.039	0.049	0	0.233	0.3505				
(3)	Cash	0.099	0.109	0	0.523	0.3122	0.3860			
(4)	Debt	0.352	0.191	0.046	0.999	-0.1103	-0.2376	-0.2500		
(5)	Investment	0.048	0.044	0.002	0.254	0.1173	-0.0719	-0.0965	-0.0098	
(6)	Profitability	0.109	0.066	-0.032	0.335	0.5113	0.0307	0.1206	-0.0289	0.2297

Table 2.2 Fixed-effect estimation of the *target equation*.

	Target equation *Equation (4)*	**Target equation 2** *Equation (5)*
rd_t	3.734***	3.703***
$cash_t$	0.918***	1.597***
$cash^2_t$	-	-1.714***
$debt_t$	-1.664***	-1.611***
$debt^2_t$	1.742***	1.699***
$investment_t$	4.184***	4.192***
$investment^2_t$	-7.767***	-7.725***
$profitability_t$	6.710***	6.688***
Const	0.908***	0.860***
F-Test	423.31	410.77
Adj R^2	0.6978	0.6982
Observations	33316	33316

All models also include year fixed effects (not reported). * p<0.1; ** p<0.05; ***p<0.01

Table 2 reports the estimation results of Equation (4) and (5), the two specifications of the *target equation*. The dependent variable in both cases is mtb_t the firm's market-to-book value (market value of assets divided by the book value of total assets); rd_t is computed as research and development expense (item 46) to total assets (item 6); $cash_t$ is cash (item 162) to total assets (item 6); $debt_t$ is liabilities (item 181) to total assets (item 6); $investment_t$ is computed as capital expenditure (item 128) to the lagged value of total assets (item 6); $profitability_t$ is operating income before depreciation (item 13) to total assets (item 6). We used the fixed-effect estimator robust to heteroskedasticity for both estimations. The dataset contains observations form year 1989 to 2013. All variables are winsorized at the 1st and the 99th percentile.

Table 2.3 Fixed effect estimation of the partial adjustment model with *target equation (4)*

	Whole sample	**R&D intensive firms**	**Non R&D intensive firms**
mtb_{t-1}	0.365***	0.336***	0.146*
rd_t	1.962***	1.935***	-3.585
$cash_t$	0.748***	0.838***	0.548***
$debt_t$	-0.784***	-1.289***	-0.243
$debt^2_t$	0.906***	1.469***	0.410
$investment_t$	1.776***	2.691 ***	0.741**
$investment^2_t$	-4.003**	-8.484***	-0.036
$profitability_t$	5.189***	5.697***	4.197***
Const	0.206***	0.250***	-0.282***
Interactions			
mtb_{t-1} x rd_t	0.357**	0.485**	-6.321***
mtb_{t-1} x $cash_t$	-0.154*	-0.183*	-0.087
F-Test	625.20	294.03	366.07
Adj R^2	0.7463	0.7155	0.7848
Observations	33315	16703	16612

All models also include year fixed effects (not reported). * p<0.1; ** p<0.05; ***p<0.01

Table 3 reports the results of the partial adjustment model estimation, using the entire sample (Column 1), only the observations about R&D intensive firms (Column 2) and only the observations about non R&D intensive firms (Column 3), respectively. The dependent variable is mtb_t, the firms'market-to-book value (market value of assets divided by the book value of total assets); rd_t is computed as research and development expense (item 46) to total assets (item 6); $cash_t$ is cash (item 162) to total assets (item 6); $debt_t$ is liabilities (item 181) to total assets (item 6); $investment_t$ is computed as capital expenditure (item 128) to the lagged value of total assets (item 6); $profitability_t$ is operating income before depreciation (item 13) to total assets (item 6). We used the fixed-effect estimator robust to heteroskedasticity. The dataset contains observations form year 1989 to 2013. All variables were winsorized at the 1st and the 99th percentile.

Table 4. Fixed effect estimation of the partial adjustment model with *target equation (5)*

	FE estimator R&D intensive firms	FE estimator Non R&D intensive firms
mtb_{t-1}	0.351***	0.360***
rd_t	2.372***	-2.328
$cash_t$	1.436***	0.922***
$cash^2_t$	-1.683***	-1.184*
$debt_t$	-1.274***	-0.236
$debt^2_t$	1.463***	0.402**
$investment_t$	2.665***	0.750**
$investment^2_t$	-8.190**	0.224
$profitability_t$	5.639***	4.202***
Const	0.227***	-0.241***
F-Test	302.57	375.98
Adj R2	0.7152	0.7843
Observations	16703	16612

The model also includes year fixed effects (not reported). * p<0.1; ** p<0.05; ***p<0.01

Table 4 reports the results of the partial adjustment model estimation, using only the observations about R&D intensive firms (Column 1) and only the observations about non R&D intensive firms (Column 2), respectively. The dependent variable is mtb_t, the firm's market-to-book value (market value of assets divided by the book value of total assets); rd_t is computed as research and development expense (item 46) to total assets (item 6); $cash_t$ is cash (item 162) to total assets (item 6); $debt_t$ is liabilities (item 181) to total assets (item 6); $investment_t$ is computed as capital expenditure (item 128) to the lagged value of total assets (item 6); $profitability_t$ is operating income before depreciation (item 13) to total assets (item 6). We used the fixed-effect estimator robust to heteroskedasticity. The dataset contains observations form year 1989 to 2013. All variables were winsorized at the 1st and the 99th percentile.

Chapter 3

Renegotiation in the Mortgage Market: is Social Welfare Maximized?

Abstract

This article analyzes the effects of mortgage renegotiations on social welfare, using a two-period model inspired by Bester (1994)'s article. A problem of asymmetric information occurs because the borrower has an incentive to lie to obtain the renegotiation. We show that, under certain conditions, only a mixed-strategy equilibrium exists. We examine the social welfare level both when it is possible to renegotiate the mortgage and when it is not, showing that renegotiation Pareto-improves total welfare, since the borrower's welfare increases while the lender's does not change. Since the lender seeks profit maximization, he has no incentive to reach the highest level of social welfare. Thus, state intervention could be socially desirable.

Introduction

This article focuses on mortgage renegotiation and its implications on social welfare. Many authors have pointed out that an inefficient number of renegotiations is offered in the mortgage market. In their work, Clauretie and Jameson (1995) inquire whether renegotiations need to be taken into account while pricing mortgages, and find that it is not necessary since they are scarce. Recently, Adelino et al. (2009), although focus more on renegotiation of mortgage–backed securities, find that renegotiations in mortgage markets during the 2008 crisis were rare. Indeed, they observe that, on a dataset that accounts for approximately 60 percent of mortgages in the United States originated between 2005 and 2007, approximately 3 percent of the seriously delinquent borrowers received a modification in the year following their first serious delinquency, while fewer than 8 percent got any type of modification. Considering that foreclosure proceedings were initiated on approximately half of the loans in the sample and completed for almost 30 percent of the sample, these numbers are fairly low.

White (2008) observes the same behavior while arguing about the effectiveness of the Hope Now Alliance's efforts, a coalition of mortgage servicers and housing counseling agencies created to stimulate a voluntary attempt to restructure mortgages.

To investigate this phenomenon, we imagine that a profit-maximizing lender decides to offer renegotiation after a cost-benefit analysis. Costs include the foreclosure cost (e.g. taking possession of the house, repairing damages, selling the house) and the chance that the borrower will lie about his income to renegotiate his mortgage, while benefits include a greater chance that the borrower will repay his mortgage.

We build a two-period model where the payoff of the initial contract is no longer optimal because of a change in the value of the house, that we assume to be stochastic, or in the income earned (assumed to be binomial).

The model is inspired by Bester (1994)'s article, which analyze the problem of debt renegotiations and how the presence of collateral may help in finding an agreement.

The Bankruptcy law we use in the model is based on the American bankruptcy law, the so-called Chapter 7. In their work, Fay et al. (2002) illustrate well how Chapter 7 protects householders who cannot be current on their mortgage any longer, although it does not help them to keep the house. The law we design allows the lender to foreclose on the house and take possession of a part of the borrower's income, until the former may recover his credit. If the borrower has a low income in the second period, he can file for bankruptcy, so the lender can only foreclose on the house but cannot recover the outstanding debt. The borrower will file for bankruptcy only when his income plus the value of the house in the second period is less than the balance due, otherwise he will sell the house and repay the mortgage. The law deters strategic default, which can be excluded from our analysis, but it does not preclude the possibility that the borrower may lie about his income. For *strategic default* we refer to that situation in which a borrower choose to default on his mortgage despite the fact that he is able to be current with his payments, because the loss of value of his house is severe and he would like to obtain a mortgage renegotiation.

If the borrower defaults because of a low income (or because he tries to obtain renegotiation, although his income is high enough to repay the mortgage), the lender can decide to propose the mortgage's renegotiation or not.

If he does not offer to renegotiate, the borrower suffers the default cost c. In their work, Guiso et al. (2011) analyze the default cost, showing that it includes all costs that follow from the decision of not repaying the mortgage, like costs of relocation, social stigma, and costs of the actions that the lender has to take against the defaulting debtor (e.g. report him to the bad debt register and the possible seizure of the borrower's assets).

In the model, a low income or a negative equity (i.e., the home's loss of value) may cause the borrower to miss his payments, but the bankruptcy law assures that he will not default strategically.

So, a borrower with a high income defaults only to lie to the lender, pretending to have a low income instead. This is a rational assumption that causes the existence of asymmetric information because the lender does not know the borrower's income.

We show that, under certain conditions, only a mixed-strategy equilibrium is possible. We use this finding to measure social welfare both when mortgage renegotiations are not allowed and when they are. We show that renegotiation Pareto-improves total welfare, because the borrower obtains a higher welfare level without affecting that of the lender. However, this means that a profit-maximizing lender has no incentive to reach the highest level of social welfare, since his profit does not change. Thus, state intervention could be socially desirable. In their work, Gerardi and Li (2010) illustrate the U.S. Government's recent efforts to prevent foreclosures and to promote renegotiations, which are consistent with our findings.

Section 1 presents the model without renegotiation and the borrower's and lender's utility functions. Section 2 presents the first case we examine, where the lender offers renegotiation and asks the whole borrower's income as repayment. Section 3 presents the second relevant case, where the lender offers renegotiation but has to ask less than the whole borrower's income. Section 4 compares the payoffs when renegotiation does not exist with those that we obtain when renegotiation is introduced. Section 5 concludes.

1. The model without renegotiation

In this section we suppose that renegotiations cannot be offered. This means that the borrower has no reason to lie about the income earned in the second period. Furthermore, there is no asymmetric information because the lender can correctly assume that the borrower does not lie, since he has no incentive.

Henceforth, we refer to the lender as "he" and to the borrower as "she".

In the model, a profit-maximizing lender grants a loan to a borrower who wants to buy a house. The lender assesses the borrower's **default cost $\boldsymbol{c}$** (that can be seen as a measure of her riskiness) by using credit scoring procedures, and then he offers a contract with a balance due $B = P_1(1 + r)$, where P_1 is the price of the house and r is the interest rate. We assume for simplicity that the principal balance is just P_1.

The price of the house is stochastic in the second period. We denote it as P_2 and its support is given by $[\underline{P}_2, \bar{P}_2]$. We indicate the distribution of P_2 as $f(P_2)$.

The borrower has no income in the first period, while the income in the second period is Y_h with probability $\boldsymbol{q}$, or Y_l with probability $\mathbf{1} - \boldsymbol{q}$**.** The use of a binomial variable to describe

We suppose that it is $Y_l < B < Y_h$, which means the borrower can pay B only when she earns Y_h. Let δ denotes the discount factor. In the model, we design a bankruptcy law based on the American bankruptcy law. The law we use allows the lender, when the borrower defaults on her mortgage, to foreclose on the house and to take possession of a part of her income, until he can recover his credit.

Specifically, the lender obtains αP_2 from foreclosing on the house (where (1-α) represents the cost of foreclosure), and he recovers the outstanding debt $B - \alpha P_2$ by seizing a part of the borrower's income Y_h.

If the borrower earns Y_l, she can file for bankruptcy, so that the lender can only foreclose on the house but cannot recover the outstanding debt. This assumption is modeled on Chapter 7 of the Title 11 of the United States Bankruptcy Code, which protects the borrower who faces an income decrease and cannot be current on her mortgage any longer.

However, P_2 could be high enough to allow the borrower to avoid foreclosure even if she earns Y_l: indeed, the borrower will file for bankruptcy only when her income plus the value of the house in the second period is less than the balance due, otherwise she will sell the house and repay the mortgage. We will discuss this case further on.

We show below that the bankruptcy law, as designed in the model, can prevent the borrower from defaulting strategically.

Since we have assumed $Y_h > B$, it is $Y_h > B - \alpha P_2$.

If renegotiation does not exist, the **borrower**'s utility function is:

$$U = \delta q \left\{ \int_{\underline{P}_2}^{\hat{P}_2} [(1-\beta)Y_h - c] f(P_2) dP_2 + \int_{\hat{P}_2}^{\overline{P}_2} (Y_h + P_2 - B) f(P_2) dP_2 \right\} + \\ + \delta(1-q)(Y_l - c),$$

where:

- β is the fraction of the borrower's income that the lender can obtain when the value of the house is not high enough to cover B;

- within the curly brackets we have the borrower's average utility that she obtains from defaulting and repaying respectively, when she earns the high income. More precisely:
  - the integral $\int_{\underline{P_2}}^{\hat{P}_2}[(1-\beta)Y_h - c]f(P_2)dP_2$ is the utility from strategic default, which happens when P_2 is between $\underline{P_2}$ and a threshold value $\hat{P}_2$ that we derive below, or $P_2 \in [\underline{P_2}; \hat{P}_2)$;
  - the integral $\int_{\hat{P}_2}^{\overline{P}_2}(Y_h + P_2 - B)f(P_2)dP_2$ is the utility from repaying, which happens when P_2 is between $\hat{P}_2$ and $\overline{P}_2$, or $P_2 \in [\hat{P}_2; \overline{P}_2]$;
- $(1-q)(Y_l - c)$ is the utility from defaulting for low income.

This function is similar to the one used by Brueckner (2000), slightly modified to take into account both the particular bankruptcy law used and the presence of a binomial income.

As in Brueckner, we can find the threshold value of P_2 that leads the borrower to strategically default by maximizing the function. Strategic default is the borrower's decision to default on a debt despite having the financial ability to make the payments.

By maximizing the borrower's utility function we find

$\hat{P}_2 = B - c - \beta Y_h$.

Henceforth, we use the **uniform distribution** to describe the house price behavior to simplify the analysis. $\hat{P}_2 = B - c - \beta Y_h$ still holds with this framework.

If $P_2 \leq B - c - \beta Y_h$, the borrower does not repay the mortgage and incurs the default cost c. If it is $P_2 > B - c - \beta Y_h$, the borrower pays B and extinguishes the mortgage.

We show below that it is $P_2 > B - c - \beta Y_h$ for every P_2 because of the bankruptcy law (that is the cause for the default cost c).

Given that $Y_h \geq B$, we can write $B = \alpha P_2 + \beta Y_h$. This equation means that the lender can recover B by foreclosing on the house, obtaining αP_2, and by taking possession of a part of the borrower's income βY_h. Since it is $B = \alpha P_2 + \beta Y_h$, we can derive $\beta = \frac{B - \alpha P_2}{Y_h}$.

Substituting for B in $P_2 > B - c - \beta Y_h$, we have $P_2 > \alpha P_2 - c$, that holds for every P_2.

We can summarize what is said above with the following proposition.

Proposition 1. Strategic default is prevented by allowing the lender to foreclose on the house and to obtain a part of the borrower's income until he can recover B.

The lender's profit function is

$$Z = -P_1 + q\eta \left[\int_{\underline{P}_2}^{\hat{P}_2} Bf(P_2)d\,P_2 + \int_{\hat{P}_2}^{\overline{P}_2} Bf(P_2)dP_2 \right] + (1-q)\eta\alpha P_2$$

where:

- η is the lender's discount factor;
- within the square brackets we have the lender's average earning when the borrower earns the high income. More precisely:
  - the integral $\int_{\underline{P}_2}^{\hat{P}_2} Bf(P_2)d\,P_2$ is the earning when the borrower defaults strategically;
  - the integral $\int_{\hat{P}_2}^{\overline{P}_2} Bf(P_2)dP_2$ is the earning when the borrower repays her mortgage;
- $(1-q)\eta\alpha P_2$ is the earning when the borrower defaults for low income.

In the first period, the lender transfers the amount P_1 to the borrower. In the second period, he obtains B with probability q (the borrower pay B or strategically default, so the lender can obtain $\alpha P_2 + \beta Y_h = B$), or αP_2 with probability $1-q$ (she earns Y_l in the second period and files for bankruptcy).

So, when renegotiation does not exist, with probability q the borrower's payoff is $Y_h + P_2 - B$, while the lender's is $B - P_1$.[1]

With probability $1-q$ the borrower has not a high enough income to repay the mortgage. However, she can sell the house and repay it, if P_2 is high enough.

[1] When the borrower earns the high income, we can derive her payoffs by adding the value of the house in the second period to her total income, and by subtracting the balance due B. The lender obtains B, but to derive his payoff we have to subtract P_1.

We assume that the borrower can sell the house at any moment without transaction costs. She chooses to sell the house and repay the mortgage when her payoff is higher than with bankruptcy.

The borrower's payoff when she sells the house and repays the mortgage is $Y_l + P_2 - B$. When she chooses to file for bankruptcy, her payoff is $Y_l - c$.[2] This means that the borrower prefers to sell the house and repay if it is $Y_l + P_2 - B \geq Y_l - c$, that can be rewritten as $P_2 \geq B - c$.

The lender's payoff when the borrower sells the house and repays is $B - P_1$, since he can recover the whole balance, while it is $\alpha P_2 - P_1$ when the borrower files for bankruptcy.

2. The model with renegotiation

We now introduce the possibility for the lender to offer renegotiation. This is an opportunity to prevent the borrower's default, so he does not offer it when the borrower earns the high income and does not lie.

When renegotiation is introduced, the borrower has an incentive to lie because she want to pay less than B, and this causes a problem of

[2] When the borrower earns Y_l, she loses the house and is left with Y_l, and suffers the default cost c. The lender obtains αP_2 with foreclosure, and we can derive his net payoff by subtracting P_1.

asymmetric information because the lender does not know the borrower's income.

In our model, renegotiation implies a repayment for the borrower, not larger than Y_l. This means that renegotiation allows the borrower to keep the house. There are two relevant cases: $P_2 > Y_l - c$ and $P_2 \leq Y_l - c$.

In the first case, the lender offers renegotiation to the borrower who claims to have earned Y_l, and ask Y_l as the renegotiated repayment. In the second case, the borrower prefers bankruptcy to pay Y_l, so the lender has to ask for less.

We can find the probabilities of these two cases by using the uniform distribution to describe the behavior of P_2. It is $P_2 > Y_1 - c$ with probability $p = \frac{\overline{P}_2 - (Y_l - c)}{\overline{P}_2 - \underline{P}_2}$ and $P_2 \leq Y_1 - c$ with probability $(1-p) = \frac{Y_l - c - \underline{P}_2}{\overline{P}_2 - \underline{P}_2}$.

2.1 First case: $P_2 > Y_l - c$

In the first case we examine, the house price in the second period is high enough to allow the lender to ask Y_l when he offers renegotiation.[3]

Proposition 1 implies that the borrower has no incentive to default strategically when she earns Y_h.

[3] We will see in sub-section 2.2 that the borrower does not always find optimal to pay Y_l.

When she earns Y_l she cannot pay B unless P_2 is high enough, so the lender has to choose between foreclosing on the house (earning αP_2 from the sale of the property) and offering renegotiation, allowing her to pay Y_l .

The mere possibility of obtaining renegotiation gives the borrower an incentive to lie on her income, because $B > Y_l$.

The decision tree is as depicted in **Figure 3.1**:

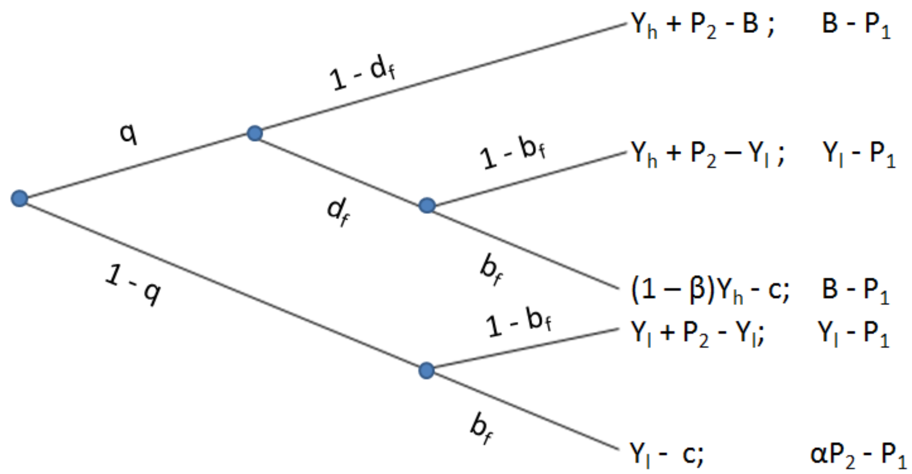

Figure 3.1: Decision tree for $P_2 > Y_l - c$

On the terminal nodes we have the borrower's and the lender's payoffs respectively.

The probability that the borrower lies when she earns Y_h is denoted with d_f, while he stays current on his mortgage with probability $1 - d_f$. The lender believes her and offers to renegotiate the mortgage with probability b_f, while $1 - b_f$ denotes the probability of foreclosure.

2.1.1. The payoffs when the income is low

We first focus on the sub-game that follows the realization of the low income.

With probability $1-q$, the borrower's income is not large enough to repay the mortgage, so she has to default, unless P_2 is high. In this case the borrower can sell the house and repay the mortgage.

The lender has two options: he can either offer to renegotiate the contract with probability b_f,, setting the repayment equal to $Y_l < B$, or he can foreclose on the house with probability $1-b_f$, obtaining αP_2.

When the lender chooses to renegotiate, the borrower's payoff is only P_2, since she pays her whole income Y_l, while the lender's is $Y_l - P_1$.

When the lender chooses to foreclose on the house, the borrower's is left with Y_l and suffers the default cost c, while the lender obtains $\alpha P_2 - P_1$. (Note that the lender cannot obtain a part of the borrower's income because the latter can file for bankruptcy).

The borrower will accept the lender's offer only if the payoff she obtains with it is larger than the one she obtains with default. This is true when $Y_l + P_2 - Y_l > Y_l - c$, or $P_2 > Y_l - c$, exactly what we have assumed in this sub-section.

If P_2 is high enough, the borrower can sell the house and repay the mortgage even if she earns Y_l in the second period.

If it happens, renegotiation does not exist, and the lender always obtains the whole balance B.

The borrower who earns Y_l sells the house when her payoff is larger than the one she obtains with foreclosure, or $Y_l - c$.

Since her payoff with sale is $Y_l + P_2 - B$, we need it to be larger than $Y_l - c$. This is true when $P_2 > B - c$.

Thus, we can state the following:

Proposition 2: For $P_2 > B - c$ there is no renegotiation, because the value of the house is high enough to allow the borrower to sell it and to repay the mortgage even if she earns Y_l in the second period.

2.1.2 The payoffs when the income is high

We now focus on the sub-game that follows the realization of the high income.

With probability q, the borrower's income is large enough to repay B, and the bankruptcy law assures that she does not strategically default, regardless of P_2.

However, the borrower would like to pay less than B, so she can lie to the lender, claiming that she has earned Y_l in the second period. Coherently to her statements, she does not repay the mortgage, hoping for renegotiation.

The risk of this strategy is that the lender forecloses on the house when he does not offer renegotiation, and he can obtain a part of the concealed income until he recovers B.

So, the borrower has two choices: she can simply pay B and extinguish the mortgage, or she can lie on her income, hoping that the lender will offer her to renegotiate the mortgage.

We denote the probability of lying as d_f, while $1 - d_f$ is the probability that the borrower repays the mortgage when she earns the high income.

As in the previous sub-section, the lender either offers renegotiation with probability $1 - b_f$, setting the repayment to Y_l, or he forecloses on the house with probability b_f, obtaining αP_2 and a part of the borrower's income, large enough to recover B.

If the borrower does not lie, his payoff is $Y_h + P_2 - B$, while the lender's is $B - P_1$.

When the borrower lies and the lender offers renegotiation, the borrower's payoff is $Y_h + P_2 - Y_l$, while the lender's is $Y_l - P_1$.

Finally, when the borrower lies and the lender does not offer her to renegotiate, the borrower loses a part of his income and suffers the default cost c, so the borrower's payoff is $(1 - \beta)Y_h - c$, while the lender's is $\alpha P_2 + \beta Y_h - P_1 = B - P_1$.[4]

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[4] The borrower's payoff is $(1 - \beta)Y_h - c$ because she has defaulted hoping for renegotiation, but it was not offered. So, she has lost the house and a part of his income, and suffers the default cost c. The lender obtains αP_2 from selling the house, and a part of the borrower's income βY_h. Since $Y_h > B$, it has to be $\alpha P_2 + \beta Y_h = B$. So, the lender's payoff is B less the amount lent P_1.

2.1.3 The renegotiation game

We show below that pure-strategy equilibria are excluded under certain conditions. The game we present is a *sequential game of incomplete information*, where the lender's posterior belief on the probability that the borrower lies can differ from d_f. Thus, the appropriate solution of this game is the Perfect Bayesian Equilibrium.

From Bayes' rule, the posterior probability that the borrower has lied about his income is

$$\pi(d_f) = \frac{qd_f}{qd_f + 1 - q}$$

We have to look for the optimal lender's behavior. Remember he can choose the probability of foreclosure b_f, with $0 \leq b_f \leq 1$.

The lender can choose $b_f = 1$, which means that he will never offer the renegotiation.

It is not certain that the borrower believes this pre-commitment, because it depends on Y_l, as it is shown below.

If the borrower knows that the lender will not offer the renegotiation, then she has no incentive to lie, so she chooses $d_f = 0$. In this case, every time the borrower claims he cannot pay, the lender knows that she has said the truth.

If $d_f = 0$ then

$$\pi(0)(B - P_1) + [1 - \pi(0)](\alpha P_2 - P_1) \quad \textbf{\textit{(1)}}$$

Expression ***(1)*** represents the lender's average payoff when she does not offer renegotiation.

$B - P_1$ is the lender's payoff when the borrower defaults to lie on his income, while $\alpha P_2 - P_1$ is the one when the borrower earns Y_l in the second period.

For $d_f = 0$, the posterior probability is $\pi(0) = 0$, so the lender obtains $\alpha P_2 - P_1$ when the borrower defaults.

Since the lender's payoff when he offers renegotiation is $Y_l - P_1$, the borrower believes $b_f = 1$ when the payoff without renegotiation is higher than the one without it, or:

$\pi(0)(B - P_1) + [1 - \pi(0)](\alpha P_2 - P_1) > Y_l - P_1$.

By simplifying this inequality, we find that the borrower believes in the lender's pre-commitment of never offering renegotiation (i.e. $b_f = 1$) when $Y_l < \alpha P_2$.

We can summarize this finding trough the following:

Proposition 3. When it is $Y_l < \alpha P_2$, there is no renegotiation, because the lender will always choose $b_f = 1$.

This is rational, because, if the borrower cannot offer anything more than αP_2, the lender has no incentive to offer renegotiation: he would obtain more by foreclosing on the house.

So, for renegotiation to exist, we need $Y_l \geq \alpha P_2$. In this case, expression (1) is larger than $Y_l - P_1$, so the pre-commitment is no longer optimal and $b_f = 1$ cannot be chosen.

Combining Proposition 2 and Proposition 3, we can state the following.

Proposition 4: For $P_2 > min\left[\frac{Y_l}{\alpha}; B - c\right]$*, there is no renegotiation, because either the lender does not find it profitable, or the borrower sells the house and repays the mortgage.*

The lender can also choose $b_f = 0$. This means that he offers renegotiation every time the borrower claims to have earned Y_l in the second period.

So, the borrower has a strong incentive to lie, and optimally chooses $d_f = 1$.

When the lender offers renegotiation, his payoff is $Y_l - P_1$, when he does not, he obtains $\pi(1)(B - P_1) + [1 - \pi(1)](\alpha P_2 - P_1)$, that can be rewritten as :

$q(B - P_1) + (1 - q)(\alpha P_2 - P_1)$.

So, the borrower believes the lender's pre-commitment only when renegotiation gives a higher payoff than foreclosure, or

$q(B - P_1) + (1 - q)(\alpha P_2 - P_1) < Y_l - P_1.$

Simplifying, it is $q < \frac{Y_l - \alpha P_2}{B - \alpha P_2}$. Note that it is $q \leq 1$ because $B > Y_l$.

Thus, we have the following:

Proposition 5. For $q < \frac{Y_l - \alpha P_2}{B - \alpha P_2}$, the lender will always prefer to offer renegotiation by choosing $b_f = 0$.

So, for $q \geq \frac{Y_l - \alpha P_2}{B - \alpha P_2}$, the lender prefers not to offer renegotiation, contradicting his pre-commitment.

This is rational: if the probability that the borrower earns Y_h is low, the lender can have a higher payoffs with renegotiation.

The reason is the following: if the lender does not offer renegotiation, he has a loss when the borrower earns Y_l (because he obtains αP_2 instead of Y_l) and has a gain when the borrower lies about her income (because he obtains B instead of Y_l).

For $q < \frac{Y_l - \alpha P_2}{B - \alpha P_2}$, the lender loses more than he gains, so he prefers to always offer renegotiation.

However, when q is high, the lender gains more than he loses, so his pre-commitment cannot be true.

Propositions 4 and 5 imply the following:

Proposition 6. For $Y_l \geq \alpha P_2$ *and* $q \geq \frac{Y_l - \alpha P_2}{B - \alpha P_2}$, *the only possible equilibrium is in mixed strategies.*

Consistent with Proposition 6, $b_f = 0$ and $b_f = 1$ are not possible equilibria, so only mixed strategies can be chosen.

To obtain the equilibrium, the lender must be indifferent between offering renegotiation and foreclosing, i.e.:

$$\pi(d_f)(B - P_1) + [1 - \pi(d_f)](\alpha P_2 - P_1) = Y_l - P_1 \qquad \textbf{\textit{(2)}}$$

The borrower's must be indifferent between lying and repaying.

Her payoff when she lies is

$$(1 - b_f)(Y_h + P_2 - Y_l) + b_f[(1 - \beta)Y_h - c].$$

Her payoff when she chooses to repay is $Y_h + P_2 - B$.

So, the borrower is indifferent between lying and repaying when:

$$Y_h + P_2 - B = (1 - b_f)(Y_h + P_2 - Y_1) + b_f[(1 - \beta)Y_h - c] \qquad \textbf{\textit{(3)}}$$

To derive the equilibrium we have to solve equations (2) and (3) for d_f and b_f, obtaining the following result:

Proposition 7: Given Proposition 6, the optimal strategies are

$$d_f^* = \frac{(1-q)(Y_l - \alpha P_2)}{q(B - Y_l)} \tag{4}$$

and

$$b_f^* = \frac{B - Y_l}{\beta Y_h + P_2 - Y_l + c} \tag{5}$$

(proof in the Appendix).

It is $d_f^* \geq 0$, and it is $d_f^* < 1$ for $q \geq \frac{Y_l - \alpha P_2}{B - \alpha P_2}$, as in Proposition 5.

Since it is $P_2 > Y_l - c$ and $B > Y_l$, we can conclude that it is $0 < b_f^* < 1$.

2.2 Second case: $P_2 \leq Y_l - c$

We consider a second case because, when $P_2 \leq Y_l - c$, the borrower does not accept to pay the renegotiated amount Y_l.

When she earns Y_l, she prefers foreclosure to pay Y_l, because she has a higher payoff filing for bankruptcy.

Indeed, her payoff is $Y_l - c$ with foreclosure, while it is P_2 with renegotiation since she is required to spend the whole Y_l to repay the renegotiated mortgage.

This means that the lender cannot ask Y_l when he offers renegotiation, because it gives the borrower a smaller payoff than default. At most, the two payoffs have to be equal, and this happens when $Y_l = P_2 + c$.

So, the lender can ask no more than $P_2 + c$ (we impose $P_2 + c = B^*$ for simplicity).

When the lender offer renegotiation, his payoff must be higher than the one he obtains with foreclosure, so we need $B^* > \alpha P_2$, which is always true[5].

Proposition 1 still holds, so the borrower will always pay when she earns Y_h, except when she lies to obtain $B^* < B$.

The decision tree is depicted in Figure 2:

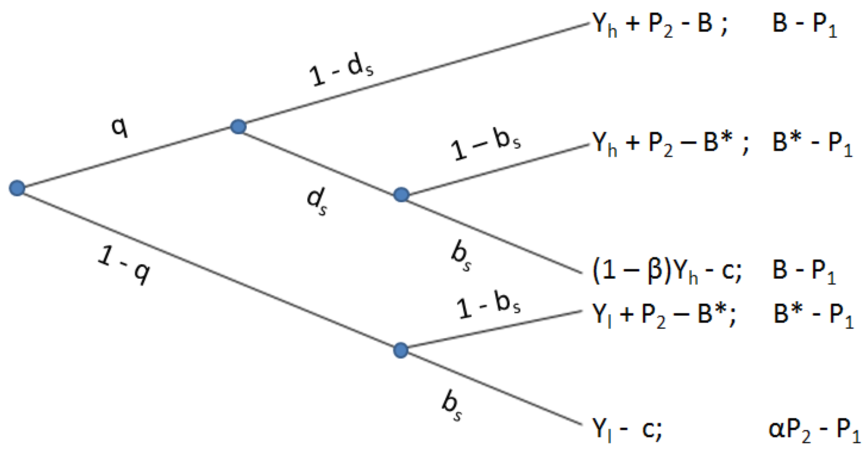

Figure 2: The renegotiation game for $P_2 \leq Y_l - c$

[5] We can rewrite $B^* > \alpha P_2$ as $P_2 - \alpha P_2 > -c$.

2.2.1. *The payoffs when the income is low*

As in the previous case, we first focus on the sub-game that follows the realization of the low income.

With probability $1 - q$, the borrower cannot repay the mortgage because his income is not large enough, so she has to default. The lender can offer to renegotiate the contract with probability $1 - b_s$, setting the repayment equal to $B^* \leq Y_l \leq B$[6], or he can foreclose on the house with probability b_s, obtaining αP_2.

If the lender choose to renegotiate, the borrower's payoff is $Y_l + P_2 - B^*$, while the lender's is $B^* - P_1$.

If the lender chooses to foreclose on the house, the borrower's is left with Y_l and suffers the default cost c, while the lender obtains $\alpha P_2 - P_1$.

As in the previous case, the lender cannot obtain a part of the borrower's income because the latter can file for bankruptcy.

2.2.2 *The payoffs when the income is high*

We now focus on the sub-game that follows the realization of the high income.

[6] $B^* \leq Y_l$ follows from $P_2 \leq Y_l - c$, because we can rewrite it as $P_2 - c \leq Y_l$, and $B^* = P_2 - c$.

With probability q, the borrower has an income large enough to repay B, and the bankruptcy law assures that there is no price P_2 that gives her a reason to strategically default.

However, the borrower would like to pay less than B, so she can lie on his income and default with probability d_s, hoping for renegotiation.

The lender will either offer her to renegotiate with probability $1 - b_s$ or foreclose on the house with probability b_s, obtaining αP_2 and a part of his income, large enough to allow him to recover B.

If the borrower does not lie, his payoff is $Y_h + P_2 - B$, while the lender's is $B - P_1$.

If the borrower lies and the lender offers her to renegotiate, the borrower's payoff is $Y_h + P_2 - B^*$, while the lender's is $B^* - P_1$.

Finally, if the borrower lies and the lender does not offer her to renegotiate, the borrower loses a part of his income and suffers the default cost c, so the borrower's payoff is $(1-\beta)Y_h - c$, while the lender's is $\alpha P_2 + \beta Y_h - P_1 = B - P_1$.

2.2.3 The renegotiation game

The posterior probability that the borrower lies about her income is

$$\pi(d_s) = \frac{qd_s}{qd_s + 1 - q}.$$

We have to look for the optimal lender's behavior.

Proposition 4 does not hold, because, as shown earlier, B^* is certainly larger than αP_2, so the lender has always an incentive to offer renegotiation.

Proposition 5 must be rewritten taking into account the new repayment B^*, so it becomes:

Proposition 8: For $q < \frac{B^* - \alpha P_2}{B - \alpha P_2}$, *the lender always offers renegotiation, by choosing* b_s *= 0.*

As in the previous case, for a q high enough, b_s *= 0* is not optimal because the lender prefers not to offer renegotiation, contradicting his pre-commitment.

Note that $\frac{B^* - \alpha P_2}{B - \alpha P_2} < \frac{Y_1 - \alpha P_2}{B - \alpha P_2}$. This is because the loss that the lender suffers when he offers renegotiation to a borrower who earns Y_2 is larger in this case than in the previous one, since he obtains $B^* < Y_l$.

Given that b_s *= 0* and b_s *= 1* are not equilibria, the only possible solution is in mixed strategies.

To derive the equilibrium, the lender must be indifferent between offering renegotiation and foreclosing:

$$\pi(d_s)(B - P_1) + [1 - \pi(d_s)](\alpha P_2 - P_1) = B^* - P_1. \qquad \textbf{(6)}$$

Note that in the first member we have the lender's average payoff when the borrower claims she earns Y_l in the second period, while in the second member we have the lender's payoff when he always offers renegotiation.

The borrower's payoff when she lies is

$(1 - b_s)(Y_h + P_2 - B^*) + b_s[(1 - \beta)Y_h - c]$,

while her payoff when she repays is $Y_h + P_2 - B$.

The borrower must be indifferent between lying and paying B^*, so

$$Y_h + P_2 - B = (1 - b_s)(Y_h + P_2 - B^*) + b_s[(1 - \beta)Y_h - c]. \qquad \textbf{\textit{(7)}}$$

To obtain the equilibrium we have to solve equations (4) and (5) for d_s and b_s:

$$d_s^* = \frac{(1 - q)(B^* - \alpha P_2)}{q(B - B^*)}$$

It is $d_s^* \geq 0$, and it is $d_s^* < 1$ for $q \geq \frac{B^* - \alpha P_2}{B - \alpha P_2}$, exactly as in Proposition 7.

We also have

$$b_s^* = \frac{B - B^*}{\beta Y_h + P_2 - B^* + c}.$$

Since it is $P_2 + c = B^*$, we find that it is $\beta Y_h + P_2 - B^* + c \geq 0$, and it is $0 < b_s^* \leq 1$ (equal only if $\beta = 0$).

3. Measuring social welfare

In this section we analyze the welfare both when renegotiation is not introduced and when it is allowed.

Although the government could value more either the borrower's welfare or the lender's, we suppose that he gives them the same importance, so we use a simple additive function to measure the social welfare.

Henceforth, we make use of the uniform density to describe the behavior of P_2.

In the 1° case is $P_2 > Y_l - c$, which happens with probability $p = \frac{\overline{P}_2 - (Y_l - c)}{\overline{P}_2 - \underline{P_2}}$.

The borrower's payoffs in this case are as follows:

	Payoffs with renegotiation	Payoffs w/o renegotiation	Difference
$\boldsymbol{q(1-d_f)}$	$Y_h + P_2 - B$	$Y_h + P_2 - B$	0
$\boldsymbol{qd_f(1-b_f)}$	$Y_h + P_2 - Y_l$	$Y_h + P_2 - B$	$-Y_l + B > 0$
$\boldsymbol{qd_f b_f}$	$(1-\beta)Y_h - c$	$Y_h + P_2 - B$	$-c-(1-\alpha)P_2 < 0$
$\boldsymbol{(1-q)(1-b_f)}$	$Y_l + P_2 - Y_l$	$Y_l - c$	$P_2 - Y_l + c > 0$
$\boldsymbol{(1-q)b_f}$	$Y_l - c$	$Y_l - c$	0

Weighting the differences with their probability we obtain:

a) $q(1-d_f)\cdot 0 = 0$

b) $qd_f(1-b_f)(B-Y_l) =$

$$= (1-q)(Y_l - \alpha P_2)\frac{(1-\alpha)P_2 + c}{\beta Y_h + P_2 - Y_l + c}$$

c) $-qd_f b_f[(1-\alpha)P_2+c]=$

$$=-(1-q)(Y_l-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-Y_l+c}$$

d) $(1-q)(1-b_f)(P_2-Y_l+c)=$

$$=(1-q)(P_2-Y_l+c)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-Y_l+c}$$

e) $(1-q)b_f\cdot 0=0$

b) and c) have the same absolute value but are opposite in sign, while d) is greater than 0. So, renegotiation gives a larger payoff to the borrower.

The lender's payoffs in the 1° case are:

	Payoffs with renegotiation	Payoffs w/o renegotiation	Difference
$\boldsymbol{q(1-d_f)}$	$B-P_1$	$B-P_1$	0
$\boldsymbol{qd_f(1-b_f)}$	Y_l-P_1	$B-P_1$	$Y_l-B<0$
$\boldsymbol{qd_f b_f}$	$B-P_1$	$B-P_1$	0
$\boldsymbol{(1-q)(1-b_f)}$	Y_l-P_1	αP_2-P_1	$Y_l-\alpha P_2>0$
$\boldsymbol{(1-q)b_f}$	αP_2-P_1	αP_2-P_1	0

Weighting the differences with their probability we obtain:

a) $q(1-d_f)\cdot 0=0$

b) $-qd_f(1-b_f)(B-Y_l)=$

$$=-(1-q)(Y_l-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-Y_l+c}$$

c) $qd_f b_f\cdot 0=0$

d) $(1-q)\left(1-b_f\right)(Y_l-\alpha P_2)=$

$$=(1-q)(Y_l-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-Y_l+c}$$

e) $(1-q)b_f\cdot 0=0$

b) and d) cancel each other out, so renegotiation leads to the same payoff as in the case without renegotiation.

Given that the borrower's payoff is higher with renegotiation, while the lender's remain the same, we can conclude that social welfare is larger with renegotiation in the first case.

In the second case it is $P_2\leq Y_l-c$, which happens with probability $1-p=\frac{Y_l-c-\underline{P_2}}{\overline{P_2}-\underline{P_2}}$.

The borrower's payoffs are:

	Payoffs with renegotiation	Payoffs w/o renegotiation	Difference
$\boldsymbol{q(1-d_s)}$	Y_h+P_2-B	Y_h+P_2-B	0
$\boldsymbol{qd_s(1-b_s)}$	$Y_h+P_2-B^*$	Y_h+P_2-B	$-B^*+B>0$
$\boldsymbol{qd_sb_s}$	$(1-\beta)Y_h-c$	Y_h+P_2-B	$-c-(1-\alpha)P_2<0$
$\boldsymbol{(1-q)(1-b_s)}$	$Y_l+P_2-B^*$	Y_l-c	$P_2-B^*+c=0$
$\boldsymbol{(1-q)b_s}$	Y_l-c	Y_l-c	0

Weighting the differences with their probability we obtain:

a) $q(1-d_s)\cdot 0=0$

b) $qd_s(1-b_s)(B-B^*)=$

$$=(1-q)(B^*-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-B^*+c}$$

c) $-qd_sb_s[(1-\alpha)P_2+c] =$

$$= -(1-q)(B^*-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-B^*+c}$$

d) $(1-q)(1-b_s)(P_2-B^*+c)=0$

e) $(1-q)b_s \cdot 0 = 0$

b) and c) have the same absolute value and are opposite in sign, so renegotiation gives the same payoff to the borrower, but he will avoid foreclosure more often, so we can conclude that the borrower is in a better situation than without the renegotiation.

The lender's payoffs in the 2° case are:

	Payoffs with renegotiation	Payoffs w/o renegotiation	Difference
$\boldsymbol{q(1-d_s)}$	$B - P_1$	$B - P_1$	0
$\boldsymbol{qd_s(1-b_s)}$	$B^* - P_1$	$B - P_1$	$B^* - B < 0$
$\boldsymbol{qd_sb_s}$	$B - P_1$	$B - P_1$	0
$\boldsymbol{(1-q)(1-b_s)}$	$B^* - P_1$	$\alpha P_2 - P_1$	$B^* - \alpha P_2 > 0$
$\boldsymbol{(1-q)b_s}$	$\alpha P_2 - P_1$	$\alpha P_2 - P_1$	0

Weighting the differences with their probability we obtain:

a) $q(1-d_s)\cdot 0 = 0$

b) $-qd_s(1-b_s)(B-B^*) =$

$$= -(1-q)(B^*-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-B^*+c}$$

c) $qd_sb_s \cdot 0 = 0$

d) $(1-q)(1-b_s)(B^*-\alpha P_2)$

$$= (1-q)(B^*-\alpha P_2)\frac{(1-\alpha)P_2+c}{\beta Y_h+P_2-B^*+c}$$

e) $(1-q)b_s \cdot 0 = 0$

b) and d) cancel each other, so the lender has the same payoff in both cases. Thus, in the second case both the borrower and the lender have the same welfare both with renegotiation and without it.

However, the borrower is in a better situation with renegotiation, since it is less likely that she will lose her house.

Taking into account both the first and the second case, we can conclude that the welfare increases when we introduce renegotiation.

Nonetheless, the lender's payoff does not change when renegotiation is introduced. Since he seeks profit maximization, we cannot be sure that he will offer the optimal amount of renegotiations. This means that a state intervention could be socially desirable.

Conclusions

This article investigates the effects of renegotiations in the mortgage market through a Bayesian game where the lender can offer the renegotiation of the mortgage, reducing the balance due B, and where the borrower has an uncertain income that is the source of asymmetric information.

We also account for the possibility that value of the house purchased with the mortgage may change, but the lender's right to foreclose on the house and to obtain a part of the borrower's income ensures that equity is not a cause of default (i.e., strategic defaults are deterred).

Our model has some simplifications needed for a more intuitive analysis. Why we are positive that, given our setting and the scope of the paper, the borrower's wage being continuous would not alter our results, additional research is needed to extend the game to a multi-period model.

There are two relevant cases that we have analyzed, that differ for the value of the house in the second period. It is shown that, under some circumstances, there is an incentive for both the borrower and the lender to use mixed strategies.

We used the optimal strategies to derive the level of the welfare both when renegotiation exists and when it does not.

We show, in the first case analyzed, that the introduction of renegotiation leads to a Pareto-improvement of the total welfare, since it increases the borrower's welfare without affecting that of the lender.

In the second case, the welfare does not change for both the borrower and the lender, but renegotiation assures that there is a lower probability for the borrower to lose his house.

Since the lender's payoff does not change with renegotiation, it is possible to conclude that he has no incentive to offer it to the borrower, and that he has no incentive to reach the maximum level of welfare: this means that the State must take the necessary steps to promote renegotiations, for example through some form of subsidy to the lender.

This is what happened in the U.S. in response to the increasing number of foreclosures caused by the sub-prime crisis, where the Department of the Treasury launched the Home Affordable Modification Program (HAMP), introduced in 2009 as part of the Making Home Affordable program (MHA), which expired on December 31, 2016. The program is focused on increasing borrowers' ability to make their monthly payments, through modifications that may include adjusting the interest rate, extending the term, and/or forgiving principal. Lenders are compensated for participation by receiving a fifty percent subsidy payment for the monthly payment reduction (capped at 3.5% of borrower monthly income) along with a lump-sum per modification (Hembre 2014).

Appendix

Proof of proposition 7

To obtain d_f^* we have to substitute $\pi(d_f)$ in equation (2), resulting in

$$\frac{qd_f}{qd_f + 1 - q}(B - P_1) + \left(1 - \frac{qd_f}{qd_f + 1 - q}\right)(\alpha P_2 - P_1) = Y_l - P_1.$$

It is $qd_f + 1 - q > 0$, so we can write as follows:

$$qd_f(B - P_1) + (1 - q)(\alpha P_2 - P_1) = (Y_l - P_1)(qd_f + 1 - q).$$

We solve for d_f^* , obtaining equation (4):

$$d_f^* = \frac{(1 - q)(Y_l - \alpha P_2)}{q(B - Y_l)}$$

We have assumed that $Y_l \geq \alpha P_2$, so $(1 - q)(Y_l - \alpha P_2) \geq 0$, and also that $B > Y_l$, so $q(B - Y_l) \geq 0$.

Thus, it is $d_f^* \geq 0$, but we need also $d_f^* \leq 1$.

So, we impose $q(B - Y_l) \geq (1 - q)(Y_l - \alpha P_2)$.

Solving for q, we obtain that equation (4) is true for $q \geq \frac{Y_l - \alpha P_2}{B - \alpha P_2}$, in accord with Proposition 4.

To obtain b_f^*, we simply have to solve equation (3)

$$Y_h + P_2 - B = (1 - b_f)(Y_h + P_2 - Y_l) + b_f[(1 - \beta)Y_h - c].$$

This can be simplified as follows

$$Y_l - B = b_f[(1-\beta)Y_h - c - Y_h - P_2],$$

obtaining equation (5):

$$b_f^* = \frac{B - Y_l}{\beta Y_h + P_2 - Y_l + c}.$$

It is $B - Y_l > 0$ because it is $B > Y_l$. It also is $\beta Y_h + P_2 - Y_l + c > 0$ because it is $P_2 > Y_l - c$ in this section.

Moreover, it is $0 < b_f^* < 1$ because it is $\beta Y_h = B - \alpha P_2$.

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