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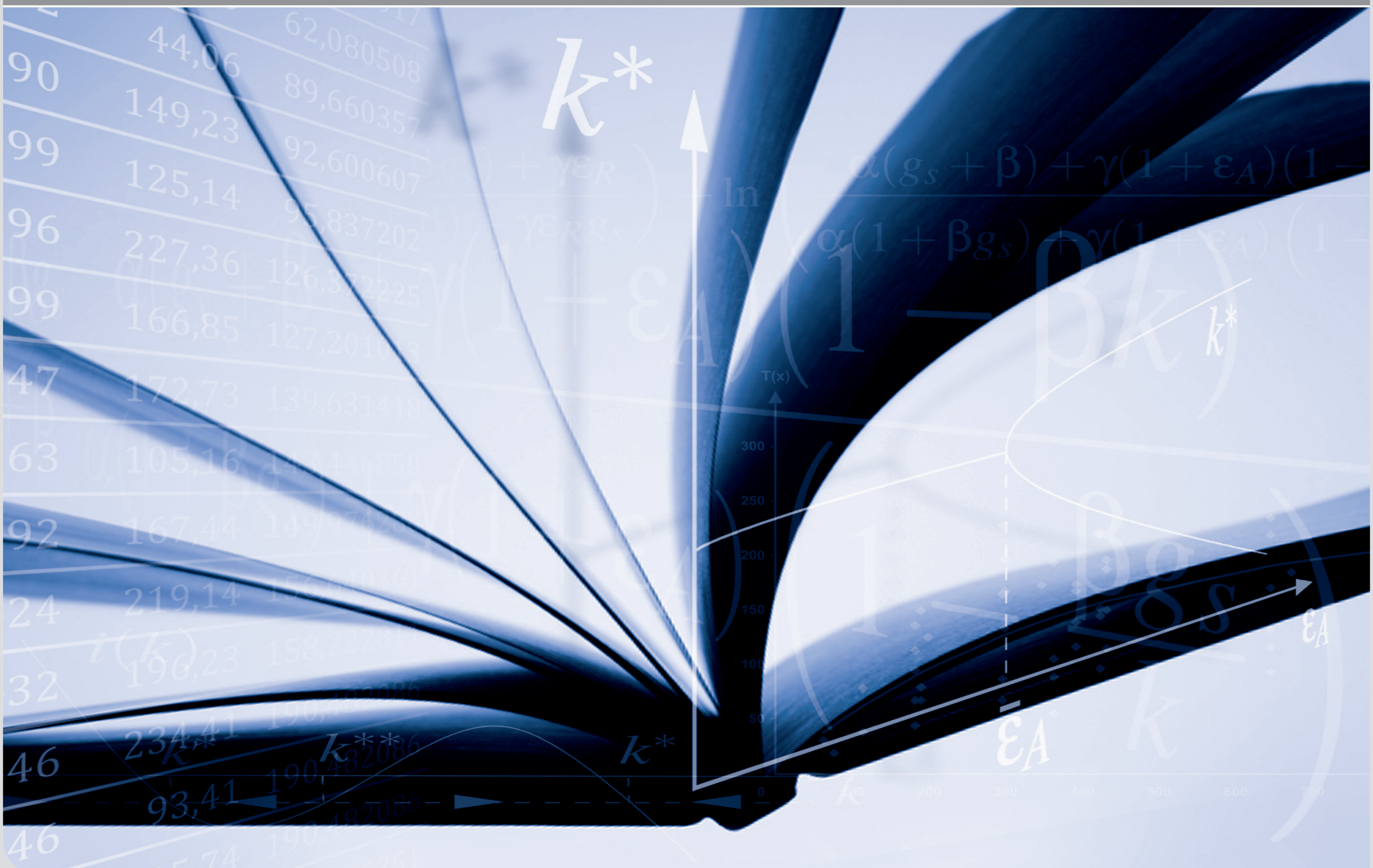

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The Blockchain, Plums, and Lemons
Information Asymmetries & Transparency in Decentralized Markets*

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Abstract

Despite a growing interest, researchers and practitioners still struggle to transfer the blockchain concept introduced by Bitcoin to market-oriented application scenarios. To shed light on the technology's usage in markets with asymmetric information, this study analyzes the effect of the blockchain's public transparency paradigm on behavioral patterns and market outcomes. In line with prior research, our findings indicate that the blockchain's shared record mitigates adverse selection effects and reduces moral hazard of good market participants (plums). In addition, we identify an incentive for bad market participants (lemons) to behave opportunistically in the presence of perfect quality information. More specifically, the disclosed information allows them to learn about quality differences between plums and lemons, deceive their counterparties, and move to a new equilibrium with increased utility. As a result, the market collapses despite a welfare gain and future generations are denied market access. In addition, plums and lemons are committed to inefficient equilibria following irrational behavior. In total, this study aims to provide initial guidance for blockchain adoption in the context of markets with information asymmetries and highlights risks that arise from competition, the exposure to irrational behavior, and the implementation of services on the infrastructure level.

JEL classification: D53, D82, G21, L86.

Keywords: Blockchain, Transparency, Market for Lemons, FinTech, Moral Hazard, Information Sharing, Credit Markets.

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1. Introduction

Despite their growing interest[1], researchers and practitioners still struggle to transfer the blockchain concept to the broader context of market-oriented applications. While few success stories, such as Bitcoin[2], pioneer financial markets, many initiatives fail to leverage the technology's potential efficiently. One major reason for this stuttering development is the limited knowledge about the economic implications of the underlying technological concepts and their relationship with the socio-economic environment, market mechanisms, and player rationales. In consequence, we aim to shed light on the technology's capability to function in market environments with information asymmetries, quality differences, and opportunistic behavior. To do so, we examine how a core feature of blockchain-based information systems - the current, complete, and publicly available record of historic transactions Notheisen, Cholewa, and Shanmugam (2017) - affects the behavioral patterns of market participants and the resulting impact on market outcomes.

From a technical perspective, the public record of past transactions enables the members of the blockchain network to validate the correctness of database updates within the consensus process. By auditing the past, they can evaluate the correctness of transactional data and determine whether the interacting parties possess rightful ownership of a transacted object. To facilitate overall data integrity, every member can participate in this process and has access to the historic record. In market environments with asymmetric information and quality differences, this new form of transparency does not only reduce uncertainty within interactions but also enables individual members to exploit the publicly disclosed information about peers and business partners to maximize their own gains. In this study, we determine under which circumstances such behavior occurs and how it affects a market in total. Thereby, we aim to identify factors blockchain adopters should consider before applying blockchain technology in market-oriented contexts and use cases.

To examine behavioral changes that come with a different information system configuration, we utilize a two-period lending game with incomplete information and entrepreneurs that choose effort levels (moral hazard) and differ in their disutility of effort (adverse selection). Our model comprises a loan market with a competitive banking sector that shares

[1] Notheisen, Hawlitschek, and Weinhardt (2017) document a rapid growth of publications in the fields of information systems, finance and economics, computer science, and law since 2014. In addition, (Lannquist, 2018) and CB Insights (2017) highlight the increasing investments of firms, and Friedlmaier, Tumasjan, and Welpe (2018) and Holotiuk, Pisani, and Moormann (2018) the growing technology market.

[2] Another example is the Australian Stock Exchange's effort to replace the current post-trade system with a blockchain-based alternative. After several testing phases and stakeholder consultations, the Australian Stock Exchange (ASX) announced in a recent media release that the current post-trade system "CHESS" will be replaced with a blockchain-based alternative that will take over core functions of clearing and settling equity transactions.

the market equally and a continuum of entrepreneurs, which is uniformly distributed on the interval $[0, 1]$. Entrepreneurs live for two periods, can be either good (a plum) or bad (a lemon), have access to a one-period project in each period, and apply for loans at a bank to fund these projects. At the end of period 1, the banks learn about the project outcomes of entrepreneurs and share this information via an information system. Eventually, dependent on the informativeness and access scope of the information system, banks and entrepreneurs can use this information to asses entrepreneurial quality.

In line with prior research, our findings indicate that sharing information about entrepreneurial performance mitigates the impact of adverse selection on the banking side and reduces moral hazard of plums by generating a disciplinary effect. In this study, we furthermore identify an incentive for lemons to behave opportunistically in the presence of value-adding information brokers. They can improve utility by using the information from the blockchain's public record to learn about the quality of plums and mimic them accordingly. Moreover, their opportunistic behavior is more pronounced for greater price improvements, lower quality differences, and lower quality in general. In opaque markets (i.e. markets without the analytic service of an information broker), neither plums nor lemons behave opportunistically. Irrespective of the information regime, plums and lemons are both locked-in to behavioral changes, and thus committed to inefficient equilibria in subsequent periods. While rational agents are not affected by this effect, the consequences of irrational decisions spill over to future periods. From a market perspective, mimicking lemons create a welfare gain under perfect information. However, their opportunistic behavior also violates the break-even condition of the banking sector, leads to a market collapse, and denies future generations' access to credit. In total, this indicates that using blockchain-based information systems in highly competitive and transparent markets with irrational agents should be considered carefully. The same holds for implementing smart contract-based analytic otherwise information-generating services on the infrastructure level.

In consequence, the contribution of this study is threefold: First, we extend the growing body of research on the economics of blockchain by analyzing the effects of the blockchain's public transparency paradigm in market environments with asymmetric information. Second, we contribute to the field of banking research by examining impact of publicly shared quality information on credit markets. And third, we add to the literature on blockchain adoption by highlighting the risks of blockchain-based transparency.

The remainder of this paper is structured as follows: Section 2 illustrates the role of transparency in the blockchain concept, reviews related literature on information sharing arrangements to extract potential blockchain implications, and highlights our research gap. Section 3 specifies the model and outlines our solution concept. Section 4 establishes behavioral patterns on the supply and demand side of the market and evaluates the potentials and effects of opportunistic behavior. In addition, section 5 discusses these findings by relaxing central model assumptions. Eventually, section 6 concludes the paper, by summarizing our findings, highlighting the implications for blockchain adoption, and illustrating future research opportunities.

2. Related Literature

This paper relates to previous research about blockchain design and examines the economic implications of the public disclosure of information essential for the technology's functioning. In this aspect, our findings relate to the growing body of research on the economics of blockchain. From a broader perspective, the transparency that comes with blockchain adoption also resembles features of information sharing arrangements present in modern financial markets. To take these commonalities into account, we embed our analyses within the context of information sharing arrangements in credit markets - a well-studied example of markets with asymmetric information - and extract blockchain-relevant implications from this body of research. In consequence, this section introduces the technological and economic aspects of transparency in the blockchain concept, briefly illustrates how credit information is currently shared, reviews the most important theoretical and empirical findings about information sharing arrangements, summarizes the resulting research gap, and formulates three research questions. A detailed overview over the characteristics of information sharing arrangements and the related literature is available in appendix C.

2.1. The Role of Transparency in the Blockchain Concept

From a technical perspective, most blockchain systems comprise three core building blocks: A distributed database, cryptographic algorithms, and a consensus mechanism (Notheisen et al., 2017). The distributed database consists of cryptographically interconnected blocks that aggregate and store transactional data and provide a copy of the ledger to every user of the system. This distributed character of the blockchain's ledger disseminates information equally to all members of the network thereby creating a new form of transparency (Catalini and Gans, 2016). Asymmetric encryption enables users to interact with the database, allows them to specify and authorize transactions via public and private keys, and ensures the unambiguous assignment of past transactions based on their unique address in the system (public key). The decentralized consensus mechanism empowers users to consensually verify and append new transactions by securely voting on their correctness based on the historical data stored in the distributed database. More specifically, within the consensus process each participating user verifies each transaction's formal correctness by checking whether it was signed by the right entities and auditing whether the sender actually owns what he or she transacts via the historical record. In the context of Bitcoin for instance, the transparency over past transactions ensures that the sender of a new transaction owns a sufficient amount of Bitcoin to cover the sending amount (Nakamoto, 2008). In more complex interactions that comprise a two-legged transaction process the review is not limited to solvency of each counterparty but may include the transacted assets attributes as well (Notheisen et al., 2017). In the case of physical assets, transaction management furthermore requires overcoming the trust frontier between the physical and digital world via a trusted interface to prevent the incorporation of corrupted information (Hawlitschek, Notheisen, and Teubner, 2018; Glaser, 2017).

To conduct a blockchain transaction, a user denominates a transactional object (e.g. a specific amount of a money or an asset), specifies a recipient (via his or her public key), references past transactions to proof ownership, signs the transaction (with his or her own private key), and broadcasts it to the peer-to-peer network. Across the network, other users collect, verify, and aggregate broadcasted transactions and propose the resulting data blocks as database updates to their peers (Eyal and Sirer, 2014)[3]. Whenever such a verified update is proposed, each participant of the consensus process checks its validity as described above before casting a vote. If a majority of the users agrees with the proposed update, the proposer appends his or her block to the blockchain, broadcasts the update to the network, and earns a reward (Nakamoto, 2008).

Building on the paradigm of public transparency, these building blocks and their functioning ensure the integrity, consistency, and correctness of data within a blockchain system and enable users to interact in the absence of a governing central authority. In markets with asymmetric information, however, transparency has implications that go beyond pure technological functionality and can lead to hidden information in the pre-contractual, and hidden action problems in the post-contractual stage (Akerlof, 1970; Stiglitz and Weiss, 1981; Hellmann and Stiglitz, 2000). In consequence, we have to take transparency implications into account, if we aim to use blockchain technology in such environments.

On one hand, the increased transparency about asset portfolios helps traders to identify

[3]In many blockchain systems a fraction of specialized users - often called miners - focuses on the update process, while others only send and receive transactions. For the sake of simplicity, we limit our analyses to a network of homogeneous nodes that all participate in the consensus process. Introducing different roles in the network would require the examination of user's incentives to fulfill those roles. This could be part of future research efforts as this study only aims to provide a first intuition of user rationales and welfare effects in market environments with asymmetric information.

suitable counterparties thereby increasing liquidity and welfare (Malinova and Park, 2017). In repeated interactions blockchain-based transparency about past behavior furthermore facilitates the stability of reputation effects by ensuring that historical records (e.g. in form of reviews and ratings) correctly reflect actual interactions and improves the auditability of the resulting digital activity trails (Catalini and Gans, 2016). From a governance perspective, blockchain technology furthermore increases transparency over ownership, and thus alleviates opportunistic behavior of individual stakeholders (Yermack, 2017).

On the other hand, the revelation of previously private information about assets' attributes and the characteristics and behavior of interacting parties may change market dynamics and induce adverse behavior of individual users. These changes affect market equilibria, the profits and utility of individual market participants, and eventually welfare (Bloomfield and O'Hara, 1999). As a result, it is crucial to consider technology-specific transparency effects in the decision whether and how to use blockchain technology in environments plagued by information asymmetries. More specifically, this includes understanding how the new transparency paradigm that comes with blockchain adoption affects economic interactions, market outcomes, and the welfare of an economy.

2.2. Lessons from Information Sharing Arrangements in Credit Markets

The information sharing arrangements used in today's credit markets allow a first glimpse on these transparency effects and their impact. In credit markets asymmetric information and the resulting uncertainty about quality lead to inefficient allocations of capital that can cause profit reductions, welfare losses, and market failures (Stiglitz and Weiss, 1981; Hellmann and Stiglitz, 2000). For small and medium enterprises for instance, empirical evidence indicates that credit rationing is more severe for more opaque firms at the beginning of their banking relationship (Kirschenmann, 2016; Dell'Ariccia and Marquez, 2004) This effect is furthermore driven by adverse selection issues and is inversely related to firm age (Hyytinen and Väänänen, 2006). For consumer credit on the other side, Karlan and Zinman (2009) find strong evidence for moral hazard and weaker evidence for hidden information issues, while informational barriers to lender competition persist (Calem, Gordy, and Mester, 2006). To mitigate the resulting issues various institutions, such as collateral (Bester, 1987), complete contingency contracts (Sharpe, 1990), or reputation systems (Diamond, 1989) developed over time. Besides these approaches, the sharing of previously private relationship information also helps to dismantle information asymmetries and alleviate the issues outlined above (Millon and Thakor, 1985). In a similar fashion, the blockchain's distributed and complete record facilitates the sharing of information - irrespective of its actually intended use.

In practice, information sharing arrangements institutionalize the provision, scope, and disclosure of information about lenders to banks and other stakeholders (Jappelli and Pagano, 2002; Djankov, McLiesh, and Shleifer, 2007; World Bank, 2011, 2013). Public credit registries are centralized databases established, owned, and managed by public entities to support their supervisory duties. As such, they provide universal coverage of loans above a specified threshold, impose participation by law, and disseminate consolidated information about an entrepreneur's riskiness to current and potential lenders and regulators. Private credit bureaus on the other hand are privately owned organizations that add significant value to credit information (Kallberg and Udell, 2003) and thereby cater to the needs of commercial lenders in their assessment of entrepreneurial risk. Participation is voluntary and based on a reciprocal agreement that offers incomplete but detailed information about loans, repayment histories, and personal backgrounds. In theory, public credit registries are set up to compensate for the lack of private arrangements (Padilla and Pagano, 2000; Jappelli and Pagano, 2002). However, in some countries both systems coexist and cater to different segments of the market (World Bank, 2013).

Theoretical predictions. Economic theory predicts that while sharing information helps to dissolve adverse selection problems and to prevent moral hazard, strategic rationales on both sides of the market are crucial factors that determine the actual effect induced by the increase in transparency. In their seminal study, Pagano and Jappelli (1993) investigate individual banks' motivation to share information and identify borrower mobility and heterogeneity, market size, and advances in information technology as positive incentives to share information. The fear of competition on the other hand impedes information sharing. In total, their model indicates that it is an efficient means to mitigate adverse selection. Padilla and Pagano (1997) build on Pagano and Jappelli (1993) and find that information sharing lowers future profits by homogenizing information among banks, while raising the chances for success today. Eventually, the resulting trade-off between increasing competition on the future and higher rents today determines the banks' willingness to share information. Bouckaert and Degryse (2006) emphasize the strategic dimension of information sharing and show that incumbent lenders limit information sharing to project outcomes in order to discourage potential entrants. Consistent with this rationale, Gehrig and Stenbacka (2007) suggest that information sharing reduces informational monopoly rents earned from relationship information but also highlight that it makes poaching more profitable (Bennardo, Pagano, and Piccolo, 2015). However, Karapetyan and Stacescu (2014) also emphasize that this loss of informational rents induces lenders to increase their investment in the acquisition of additional information in order to regain their monopoly. From a market perspective, Bennardo et al.

(2015) predict that sharing information improves coordination among lenders and thereby decreases entrepreneurs incentive to overborrow when lending from multiple banks. As a result, interest and default rates decrease and the access to credit improves. In the case of distress however, intensified lender coordination increases default probabilities even further (Hertzberg, Liberti, and Paravisini, 2011).

In contrast to these studies, Padilla and Pagano (2000) focus on the entrepreneurial effects of information sharing. While sharing information about entrepreneurs raises their incentive to perform, it also creates a disciplinary effect as hazardous behavior impedes the ability to obtain credit from other sources as well. However, Padilla and Pagano (2000) also find that sharing too much information can eliminate any disciplinary effects, because entrepreneurs' true types are revealed. In consequence, lenders need to tailor the type and accuracy of information to balance the trade-off between adverse selection and moral hazard effects in order to incentive entrepreneurs to perform on their optimal level. Diamond (1989) and Vercammen (1995) examine on specific aspects of such disciplinary effects in greater detail: Diamond (1989) studies the formation and evolution of reputation effects and indicates that reputation needs time to establish. In contrast, Vercammen (1995) - who assesses the impact of credit bureau policy on entrepreneurial efforts - finds that the resulting improvement of welfare does not hold over time, because lenders become increasingly aware of entrepreneurial types as credit histories lengthen. A similar effect emerges with the increasing informativeness of consumer credit reports. More specifically, Sharma (2017) illustrates that the probability of strategic defaults is higher when the information content of credit reports is more likely to reveal entrepreneurial types.

Empirical evidence. Empirical studies aim to provide complementary evidence for these theoretical predictions and evaluate the economic impact of information sharing arrangements in a broader context. Brown and Zehnder (2010) for instance transfer the model of Pagano and Jappelli (1993) to an experimental setup and confirm their findings as more asymmetric information facilitates information sharing, while stronger competition has an impeding effect. In addition, Doblas-Madrid and Minetti (2013) utilize contract-level data from the US to study the effects predicted by Padilla and Pagano (1997) and Padilla and Pagano (2000) and find - consistent with theory - that the entry into a credit bureau reduces contract delinquencies and defaults. Similarly, Jappelli and Pagano (2002) demonstrate that lending volume is higher and credit risk lower in countries where lenders share information.

From an individual's perspective, the existence of an efficient information sharing arrangement reduces firms' financing obstacles significantly (Beck, Demirg-Kunt, and Maksimovic, 2004) as credit bureaus add significant explanatory power to failure prediction models (Kallberg and Udell, 2003). Dierkes, Erner, Langer, and Norden (2013) confirm this effect channel and indicate that a prediction's accuracy increases with firm age, credit bureau experience, and the spatial distance between firm and credit bureau and decreases with firm size. With respect to private credit, Djankov et al. (2007) find that private credit bureaus are more likely in richer and public credit registries are more likely in poorer countries. Moreover, the introduction of an information sharing arrangement increases the volume of private credit in both. In total, these results support previous findings (e.g. Jappelli and Pagano (2002), Pagano and Jappelli (1993), or Padilla and Pagano (1997)) and highlight the beneficial role of information sharing in developing countries with poor creditor rights. However, Bos, Breza, and Liberman (2018) also identify a causal effect of negative credit information on employment and wage levels.

Brown, Jappelli, and Pagano (2009) find similar effects for corporate loans and provide empirical evidence that information sharing improves the access to and lowers the cost of credit - especially for opaque ventures. However, Behr and Sonnekalb (2012) are not able to confirm these results for public credit registries but find a positive effect on loan performance. This effect is more pronounced for repeated interactions and areas with low competition, which supports the disciplinary effect predicted by Padilla and Pagano (2000) A similar ambiguity prevails for the volume effects identified in theoretical and empirical research (e.g. Padilla and Pagano (2000), Djankov et al. (2007), or Allen and Santomero (1997)). Grajzl and Laptieva (2016) find no evidence for a volume effect with respect to public credit registries whereas, private credit bureaus on the other hand are associated with an increase in lending volume. Furthermore, extending the provision of credit information to borrowers creates an awareness about financing costs and reduces credit volume and overborrowing issues (Bertrand and Morse, 2011).

In addition, there are several studies that examine the effects of information sharing arrangements from a banking perspective. Barth, Lin, Lin, and Song (2009) for instance, provide strong evidence that private credit bureaus reduce lending corruption and enhance the curtailing effect of bank competition on lending corruption. Moreover, Houston, Lin, Lin, and Ma (2010) support Hertzberg et al. (2011)'s coordination hypothesis and indicate that information sharing decreases banks' risk-taking. This leads to positive effects on bank profitability, bank risk, the likelihood of financial crises, and economic growth. Buyukkarabacak and Valev (2012) furthermore confirm the positive effect on banking crises for both, public and private information sharing arrangements. On the other hand, Giannetti, Liberti, and Sturgess (2017) underline the strategic rationales illustrated by Bouckaert and Degryse (2006) and show that banks manipulate shared credit information to protect profitable customer segments.

Blockchain implications. In total, the reviewed literature on information sharing arrangements offers several valuable insights with respect to blockchain technology: First, it helps us to understand the capability of the blockchain's record to share information. The studies of Kallberg and Udell (2003) and Dierkes et al. (2013) for instance indicate that sharing information via the blockchain's distributed and complete record of past transactions provides an efficient tool to mitigate problems caused by pre- and post-contractual information asymmetries (Padilla and Pagano, 2000; Beck et al., 2004) and facilitate coordination among users (Bennardo et al., 2015; Hertzberg et al., 2011; Bertrand and Morse, 2011; Brown and Zehnder, 2010). However, to ensure a positive impact, it is important to fine-tune the (time) scale (Diamond, 1989; Vercammen, 1995) and (content) scope (Padilla and Pagano, 2000; Bouckaert and Degryse, 2006) of disclosed information carefully. A special challenge for instance poses the impossibility to delete past transactions, because the disciplinary effects fade with lengthening records Vercammen (1995). On the other hand, the blockchain's immutable and tamper-free nature prevents and thereby reduces the effects of data manipulation (Giannetti et al., 2017) - at least in the digital world (Hawlitschek et al., 2018). Second, it outlines potential channels through which a change in transparency characteristics might influence behavioral patterns and market outcomes. More specifically, using a consensually updated and shared database tightens competition (Pagano and Jappelli, 1993), dilutes informational monopolies (Padilla and Pagano, 1997, 2000; Bouckaert and Degryse, 2006), and improves market access, volume, and efficiency (Djankov et al., 2007; Brown et al., 2009). In addition, sharing previously private information on the supply side redistributes rents to the demand side (Padilla and Pagano, 1997) and creates a disciplinary effect that alleviates opportunistic behavior (Padilla and Pagano, 2000). The trade-off between those effects determines the impact on welfare, the motivation to share information, and strategic rationales on both sides of the market (Bouckaert and Degryse, 2006; Sharma, 2017).

2.3. Research Gap and Research Questions

Despite these commonalities, there is also a crucial difference between the information system traditional information sharing arrangements are built on and blockchain-based information systems: Traditional arrangements built on centralized information systems provide a specific scope of information to a selected group of users. In consequence, banks have access to information about the complete market, while entrepreneurs can only access information about themselves. The blockchain concept on the other hand does not curtail the access rights of individual users and discloses the stored information publicly. This way, blockchain-based systems ensure data integrity and facilitate the validity of database updates in the absence of a central authority. As a result, all users have the same level of information.

Thus, to fully leverage the blockchain's potential, it is crucial to understand potential side effects that come with the shift to public transparency. More specifically, in markets with asymmetric information and quality differences increasing transparency does not only reduce uncertainty but also enables opportunistic users to exploit quality information in order to maximize their individual gains. To shed light on the underlying behavioral patterns and outcomes and to identify potential risks of blockchain adoption, we formulate the following research questions:

Research question 1. *How does the public availability of quality information affect the behavior of individual participants on the demand side of the market?*

Within the related analyses, we investigate who changes behavior, how and why these changes occur, and evaluate the resulting outcomes. To do so, we take the perspective of both plums and lemons and examine the incentives to change behavior, the consequences that come with changes and dismantle effect channels over time. In addition, we consider different system configurations and connect individual outcomes to characteristics of the socio-economic environment. However, the effect of behavioral changes is not limited to individuals but also spills over to the market and the economy as a whole.

Research question 2. *How do behavioral changes of individual market participants on the demand side affect the economy and the market's functioning as a whole?*

This research question covers welfare effects as well as the impact on the supply (banking) side of the market. In consequence, we examine whether the aggregated behavioral changes of individual market participants improve or impede welfare and which factors drive these effects. To analyze the markets functioning, we furthermore take a closer look at the impact of behavioral changes on the supply side (i.e. banks) of the market. Eventually, it is also important to transfer the findings from research questions 1 and 2 to a practical application context to support researchers and practitioners in their blockchain endeavors.

Research question 3. *What aspects do we need to consider when using blockchain technology in market-oriented application contexts exposed to information asymmetries?*

3. The Model

Economy. There is a loan market with a competitive banking sector with $b > 1$ immortal banks and a continuum of entrepreneurs, which are uniformly distributed on the interval $[0, 1]$. Entrepreneurs live for two periods, are either plums (good) or lemons (bad), have access to one-period investment projects in each period, and apply for loans at the banks to fund these projects. They furthermore can choose a bank at the beginning of each period at zero costs. When new entrepreneurs come to a bank, the bank has no knowledge about their type. However, banks can gather information about entrepreneurial characteristics through their lending relationship (Boot and Thakor, 2000; Boot, 2000), as they observe project outcomes at the end of each period. In addition, banks share the observed default information via an information system at the end of period 1. This way they aim to reduce the information asymmetries they face when entrepreneurs switch banks and use the information acquired from the information system to approximate types (Padilla and Pagano, 2000). All actors are risk-neutral and act as rational economic agents. Figure 1 illustrates the sequence of actions in the economy in greater detail.

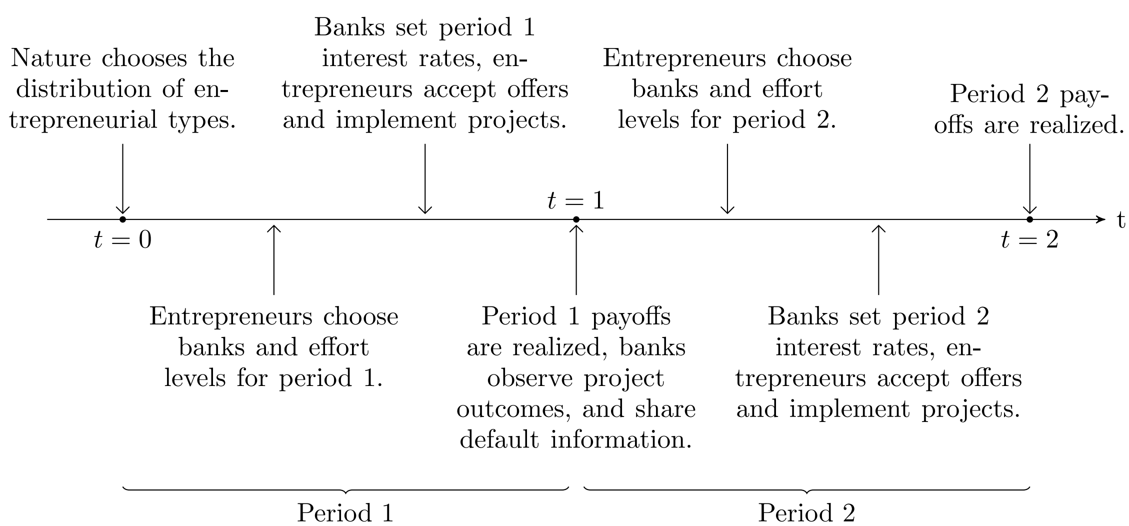


Fig. 1. Timeline of actions

Information system. The information system functions as a means to periodically share information, stores default information over time, and makes it available to its users. This way it enables banks to assess entrepreneurs based on historic averages of past generations. However, the accuracy of this assessment depends on the informativeness of the conveyed data. To represent this dependency in our model we define two information regimes: Imperfect and perfect information. In the imperfect information regime, the information system supplies plain default information. Under perfect information on the other hand, an information broker - for instance in form of a private credit bureau or a rating agency - adds value in form of type information to the default data. As a result of this analytic assessment, banks can identify entrepreneurial types by comparing actual period 1 efforts with historic averages. In addition, the system can either be deployed as a traditional data base or as a blockchain-based information system. In the first case, banks have full access, while entrepreneurs can only see their own performance record. In the blockchain case on the other hand, all users have access to all data.

Entrepreneurs. Entrepreneurs have no initial funds and access to a one-period investment project in each period. This project requires an initial investment of 1 at the beginning of a period and yields a positive return $R > 1$ at the end of a period, if successful. In the case of failure, it yields a return of 0 and the entrepreneur defaults. A project's probability of success $p_i \in [0, 1]$ depends on the entrepreneur's type $i \in \{H, L\}$, is monotonic in the effort exercised by an entrepreneur[4], and creates a quadratic disutility of effort $V_i(p(i)) = a_i p_i^2$ with a cost parameter $a_L > a_H > 0$. The disutility of effort is a strictly convex function with $V' \in [0, \infty)$ and $V'' > 0$ and represents the costs an entrepreneur has to bear to achieve a specific success probability p_i. Intuitively, this reflects the idea that plums posses greater entrepreneurial skills compared to lemons. As a result, effort is always cheaper for plums but never costless for both types. More specifically, plums' greater talent $\Delta a = a_L - a_H > 0$ allows them to achieve either greater productivity levels $p_H > p_L$ at a given cost $\bar{V} = V_H(p_H) = V_L(p_L)$ or some success probability $\bar{p} \in (0, 1]$ at lower costs $V_H(\bar{p}) < V_L(\bar{p})$. In addition, the marginal costs of effort are higher for bad than for good entrepreneurs $V_L'(\bar{p}) > V_H'(\bar{p})$. For $p = 0$, the disutility of effort is equal to zero for both types ($V_L(0) = V_H(0) = 0$).

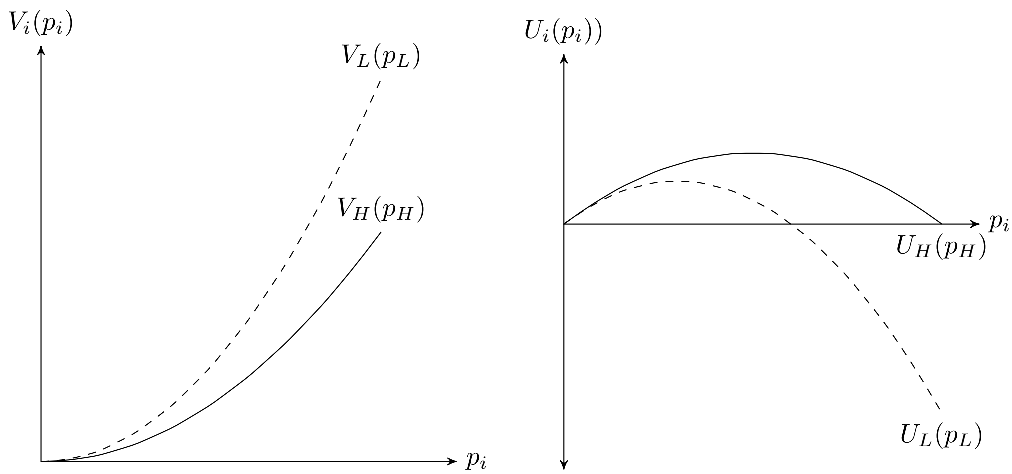
In total, entrepreneurs experience utility from successful projects and choose their individual levels of effort p_i to maximize their expected utility over both periods, while taking the effort choices of other entrepreneurs as given. They furthermore act as price takers and take the interest rates offered by the banks as given. Eventually, an individual entrepreneur's utility is equal to:

$$U_i(p_{i,1}, p_{i,2}) = \underbrace{p_{i,1}(R - R_1) - V_i(p_{i,1})}_{\text{Net return period 1}} + \underbrace{p_{i,2}\big(R - E[R_2]\big) - V_i(p_{i,2})}_{\text{Expected net return period 2}}, \text{ with } i \in \{H, L\}. \tag{1}$$

In period 1, $p_{i,1}$ denotes effort, $V_i(p_{i,1})$ the corresponding disutility, and R_1 the repayment (principal and interest) to the bank. The same logic applies to period 2, while $E[R_2]$ repre-

[4]Similar to (Padilla and Pagano, 1997) this allows us to interpret p as the entrepreneurs choice variable.

sents the expected interest rate given the behavior in period 1[5]. If an entrepreneur does not get any credit, his or her expected utility is equal to zero. Figure 2 illustrates the 1-period cost (2(a)) and utility (2(b)) functions of plums and lemons respectively.



(a) Disutility of effort

(b) Utility

Fig. 2. **Entrepreneurial disutility and utility:** Functional form of the partial disutility of effort and partial utility for one period.

As illustrated in figure 1, entrepreneurs choose their effort levels prior to borrowing in each period, while their effort is non-observable and non-contractible[6]. As a result, interest rates cannot be conditioned on an individual entrepreneur's probability of repayment. However, interest rates will depend on the average ex-ante repayment probability of previous generations, which is accessible via the information system. In addition, project returns are observable and contractible by the lending bank[7].

Eventually, the fraction of plums in the market is denoted by the uniformly distributed random variable $\theta \in (0, 1)$[8]. This distribution of plums and lemons is common knowledge. The historic average success probabilities of each type are known to the lending banks in the traditional information sharing regime and common knowledge in the blockchain regime.

[5]Note that the sub- and superscripts will be more detailed in the following sections and change according to the analytic scenarios (i.e. information regimes and switching). However, for the sake of simplicity, we refrain from reporting all sub- and superscripts here

[6]Practical examples include hiring a good manager, preparing a good business plan, or the potential of a project itself. For outsiders and non-experts, such as lending banks, these activities and project characteristics are hard to verify. In addition, their qualitative nature makes them hard to enforce in court (Padilla and Pagano, 2000).

[7]Contractibility of project returns ensures that in case of success the entrepreneur must repay the loan, while their observability ensures that the actual project outcome (i.e. success or default at the end of a period) is only observed by the lending bank and not any outside banks.

[8]This ensures that there is at least one plum or lemon in the market.

Banks. Banks can raise funds for one period at a gross interest rate of $R \geq \bar{R} > 1$ (principal and interest) at the beginning of each period[9], offer one-period loan contracts to the entrepreneurs, and compete in interest rates. Consequently, each bank maximizes its expected profits given the average probability of success of plums and lemons by setting the interest rates in period 1 and 2.

While providing credit, banks face adverse selection ex-ante due to the non-observable and moral hazard ex-post due to the non-contractible nature of entrepreneurial effort levels. During the initial engagement with an entrepreneur in period 1, banks can observe project outcomes and share this information with each other at the end of period 1. To mitigate the adverse selection problems in the imperfect information regime, they use the Bayes' Rule to update their beliefs based on shared default information. In the case of perfect information, they can acquire type information at zero costs. Conditional on the level of information about entrepreneurial quality, their expected profit in each period of a bank is equal to

$$E\left[\Pi_t\right] = \frac{1}{b}\left[\theta p_{_H} R_{j,t} + (1-\theta) p_{_L} R_{j,t} - \bar{R}\right], \text{ with } j \in \{H, L, P\} \text{ and } t \in \{1, 2\}. \tag{2}$$

At the beginning of period 1, banks have no information about entrepreneurial quality and compete for the whole market. As a result banks are unable to differentiate between plums and lemons, offer a pooling rate $R_{P,1}$, and share the market equally. In period 2, banks still compete in prices and share the market equally but have more information about entrepreneurs. In consequence, they offer either risk-adjusted pooling rates $R_{P,2}(0)$ and $R_{P,2}(R)$ conditioned on default under imperfect or type-specific rates $R_{H,2}$ and $R_{L,2}$ under perfect information.

Solution concept. In order to analyze the impact of the blockchain's public record, we examine and compare the following combinations of information regimes and access scope: While banks have either imperfect or perfect information and always have access to the information system, entrepreneurs stay uninformed with a traditional access scope. In the blockchain regime on the other hand, public access to the information systems system enables entrepreneurs to learn about the average success probabilities of plums and lemons. Comparing these two information regimes and access scopes allows us to examine the extent to which the quality and availability of information provokes behavioral changes of plums and lemons. To do so, we look for subgame perfect equilibria by applying the following

[9] This assumption requires banks to pay back their funds at the end of each period and roll over to new funding at the beginning of the next period. If they cannot repay funds at the end of a period, they go bankrupt an have to quit business. As a result they set their interest rates to break even in each period independently of other previous or following periods.

rationale:

- Banks act simultaneously and maximize their profits by setting period 1 and 2 interest rates given the average historic success probabilities of plums and lemons p_H and p_L. In consequence, the vectors $(R_{P,1})$, $(R_{H,2}, R_{L,2})$, and $(R_{P,2}(0), R_{P,2}(R))$ constitute a subgame perfect equilibrium for the banking subgames in period 1 and 2 respectively.
- Entrepreneurs choose their individual effort levels $p_{i,t}$ simultaneously to maximize their expected utility over both periods, correctly anticipating the interest rates in period 1 and 2, while taking the effort levels of the other entrepreneurs as given.

Remarks. Note that while the distribution of entrepreneurial types and their average success probabilities are common knowledge among banks, the allocation of good and bad entrepreneurs to the market fractions $[0, \theta]$ and $(\theta, 1]$ needs to be observed in period 1. Intuitively speaking, banks know how many good and bad entrepreneurs are in the market and the difference Δa between them but are not able to distinguish between them on an individual level. To focus on the impact of the non-discriminatory disclosure of information that comes with blockchain usage, we do not vary the scope of the information sharing arrangement.

To keep the model simple, neither banks nor entrepreneurs discount profits or utility, we do not consider costs for information acquisition or sharing, and each entrepreneur's wealth is equal to zero when applying for a loan[10]. Furthermore, note that while past defaults do not have any impact on the investors' wealth level, information about past defaults does as it is recorded and shared by the lending bank. To improve accessibility and readability, a list of variables, their scope, and a brief description is given in the appendix A.

[10]More specifically, we assume that the entrepreneurs consume the profits of successful projects immediately, and thus start with no collateral or any other capital from previous projects. In case of default, the bank forgives the debt at the end of each period as an investment project represents a separate limited liability company.

4. Analyses

As stated before, a core feature that enables blockchain-based systems to function independently from central authorities is the public availability of the underlying transactional database. However, besides reducing adverse selection effects and moral hazard on the banking side, access to the blockchain's historic record also enables entrepreneurs to gather information about each others qualities. As a result, public system access allows individual entrepreneurs to direct their behavior in order to deceive banks and facilitate misjudgment. To analyze whether and how this potential for deception might affect markets' functioning and outcomes, we establish the banking perspective in the first subsection (4.1). In section 4.2, we build on the resulting interest rates to investigate the motivation of switching and staying plums and lemons to mimic their respective counterparts given different information system configurations. Eventually, section 4.3 combines both perspectives and examines the welfare effects of increased transparency that comes with blockchain adoption on a market level. Appendix B provides proofs of propositions 1 to 12 (B.1) and supportive calculus for the profits and the utility of banks and entrepreneurs (B.2).

4.1. Banking Perspective

To establish the market environment for entrepreneurs, we characterize the banking equilibrium first. To find the equilibrium rates charged in a partly competitive market with shared default information, we build on the approaches of Padilla and Pagano (1997) and Padilla and Pagano (2000) and use backward induction, while taking entrepreneurial effort levels and quality differences as given. To simplify our analyses, we assume that the entrepreneurial effort levels p_H and p_L are exogenously given and that $p_H > p_L$.

The banks set period 1 and period 2 interest rates to break even given their cost of capital $\bar{R}$ and entrepreneurial efforts p_H and p_L, while competition erodes monopoly rents. At the beginning of period 2, entrepreneurs can switch banks and banks use the information about period 1 to assess entrepreneurial quality and charge risk-adjusted interest rates in period 2. In the case of imperfect information (i.e. default information), the information system allows the banks to separate defaulters and non-defaulters and Bayesian learning leads to two pooling equilibria. For perfect information on the other hand, banks can acquire type information based on period 1 performance from the information system to separate plums and lemons and charge adequate interest rates. In period 1, the absence of information leads to a uniform pooling rate. From this starting point, we apply backward induction in order to find the equilibrium interest rates within each information regime and period.

4.1.1. Assessment of Entrepreneurs with Imperfect Information

Suppose that the banks share the market equally in period 1, each bank observes project outcomes at the end of period 1, and shares default information consequently. At the beginning of period 2, each bank accesses the information system and utilizes the default information to offer entrepreneurs a pooling rate conditional on period 1 project outcomes. More specifically, the bank uses Bayes' rule, to approximate whether a customer is good or bad conditional on period 1 default and given the distribution of types and their average success probabilities. Figure 3 illustrates the resulting probability structure. Based on this structure, $\mu(H|R)$ denotes a bank's posterior belief at the beginning of period 2 that an entrepreneur who was successful in period 1 is a plum. Conversely, $\mu(H|0)$ is the posterior probability of being a plum conditional on failure in period 1. The posterior probabilities for lemons follow the same idea. Using Bayes' theorem, the posterior success probabilities

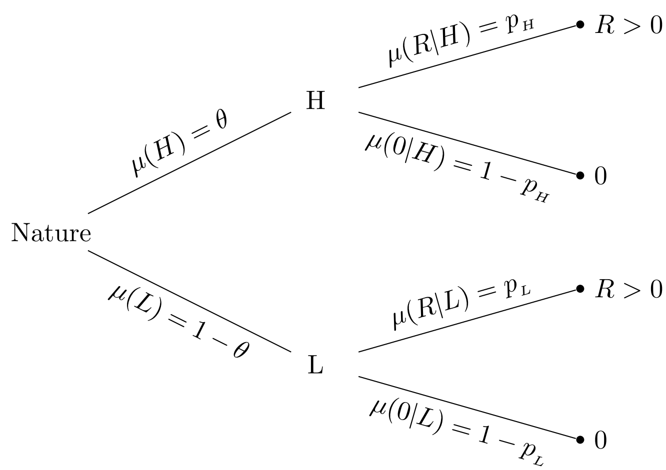


Fig. 3. **Probability structure:** Structure of a priori success probabilities of plums and lemons.

of plums and lemons are equal to equations (3), (4), (5), and (6) conditional on success and default in period 1. Moreover, the update beliefs can be interpreted as the probability that a bank identifies plums and lemons correctly given period 1 project outcomes.

$$\mu(H|R) = \frac{\mu(R|H)\mu(H)}{\mu(R)} = \frac{p_H\theta}{\theta p_H + (1-\theta)p_L}, \tag{3}$$

$$\mu(L|R) = 1 - \mu(H|R) = \frac{p_L(1-\theta)}{\theta p_H + (1-\theta)p_L} \tag{4}$$

$$\mu(H|0) = \frac{\mu(0|H)\mu(H)}{\mu(0)} = \frac{(1-p_H)\theta}{\theta(1-p_H) + (1-\theta)(1-p_L)}, \tag{5}$$

$$\mu(L|0) = 1 - \mu(H|0) = \frac{(1-p_L)(1-\theta)}{\theta(1-p_H) + (1-\theta)(1-p_L)} \tag{6}$$

Proposition 1 implements this notion and formalizes the banks' perception of project risk in period 2. Intuitively speaking, this means that in a market with both types and lending not all plums will be successful and not all lemons will default, while the probability for success (default) is higher for plums (lemons). As a result, default information is helpful to approximate effort levels but not as good as having perfect information.

Proposition 1. *Sharing default information at the end of period 1 enables banks to approximate the quality of entrepreneurs but still bears the risk of an incorrect assessment. As a result, banks regard defaulted entrepreneurs as riskier, underestimate the success probabilities of defaulters, and overestimate the one of non-defaulters on average.*

$$p_H > \mu(H|R)p_H + \mu(L|R)p_L > \theta p_H + (1-\theta)p_L > \mu(H|0)p_H + \mu(L|0)p_L > p_L$$

4.1.2. Period 2 Interest Rates

Imperfect information. To determine the interest rates offered in period 2, the banks utilize the default information from the information system to adjust its beliefs about plums and lemons. In consequence, they weight the success probabilities of defaulters with $\mu(H|0)$ and $\mu(L|0)$ and the success probabilities of non-defaulters with $\mu(H|R)$ and $\mu(L|R)$ and a bank's expected period 2 profits are equal to

$$\begin{aligned} E\big[\Pi_2\big] = &\frac{1}{b}\Big[\underbrace{\big(\theta p_H + (1-\theta)p_L\big)}_{\text{Fraction defaulters}}\underbrace{\big(\mu(H|0)p_H + \mu(L|0)p_L\big)R_{P,2}(0)}_{\text{Expected profit defaulters}} \\ &+ \underbrace{\big(\theta(1-p_H) + (1-\theta)(1-p_L)\big)}_{\text{Fraction non-defaulters}}\underbrace{\big(\mu(H|R)p_H + \mu(L|R)p_L\big)R_{P,2}(R)}_{\text{Expected profit non-defaulters}} - \bar{R}\Big] \end{aligned} \tag{7}$$

Competitive pressure ensure that expected profits are equal to 0 and each bank offers the following pooling rate to defaulters:

$$R_{P,2}(0) = \begin{cases} \frac{\bar{R}}{\mu(H|0)p_H + \mu(L|0)p_L} & \text{if } p_i' \le p_i \le p_i'', \\ R & \text{if } \frac{\bar{R}}{R} \le p_i < p_i'(0) \text{ or } p_i'' < p_i \le 1, \\ \text{no lending,} & \text{otherwise.} \end{cases} \tag{8}$$

In equation (8), p_i' and p_i'' represent the minimum success probabilities that solve the quadratic break-even condition $\big(\mu(H|0)p_{_H} + \mu(L|0)p_{_L}\big)R_{P,2}(0) - \bar{R} \overset{!}{=} 0$ when both types exercise positive effort levels ($p_{_H} > p_{_L} > 0$). For success probabilities outside of these intervals, the pooling rate would exceed the expected return to successful entrepreneurs, and thus the banks cannot charge more than the project return R.

The same logic applies to successful entrepreneurs and thus the interest rate offered to them is equal to

$$R_{P,2}(R) = \begin{cases} \frac{\bar{R}}{\mu(H|R)p_{_H} + \mu(L|R)p_{_L}}, & \text{if } p_i'' \leq p_i \leq p_i'' \\ R, & \text{if } \frac{\bar{R}}{R} \leq p_i < p_i' \text{ or } p_i'' < p_i \leq 1 \\ \text{no lending}, & \text{otherwise}, \end{cases} \tag{9}$$

while p_i' and p_i'' solve the bank's break-even condition for successful entrepreneurs $\big(\mu(H|R)p_{_H} + \mu(L|R)p_{_L}\big)R_{P,2}(R) - \bar{R} \overset{!}{=} 0$. Again, banks cannot charge more than the full project return R for values of p_i outside the optimal intervals. In both cases default and success non lending occurs for effort levels below $\frac{\bar{R}}{R}$. This also includes situations, where only one type exerts positive effort and the other exerts no effort at all (i.e. $p_{_H} = 0$ or $p_{_L} = 0$).

If one bank would undercut its rivals and charge interest rates below $R_{P,2}(0)$ or $R_{P,2}(R)$ it would win the competition but make a loss on average. More specifically, undercutting $R_{P,2}(0)$ would draw all defaulters and undercutting $R_{P,2}(R)$ all successful entrepreneurs. However, neither of these rates complies with the bank's break-even condition, as they both would underestimate the actual distribution of plums and lemons among defaulters and non-defaulters. For interest rates greater than $R_{P,2}(0)$ or $R_{P,2}(R)$, no entrepreneur would agree to lend and the offering bank would not be able to repay its funding and simply go out of business. In total, banks do not earn any rents on entrepreneurs as the expected gains on plums are offset by the expected losses generated by lemons mixed in the pools of defaulters and non-defaulters.

Perfect information. In contrast to imperfect information, an information system with value-adding information broker allows each bank learn about the types of entrepreneurs before offering interest rates in period 2. This type information enables them to separate plums and lemons and charge perfectly discriminatory prices conditional on the type assessment in period 1. In consequence, period 2 profits in the perfect information regime are add up to

$$E\big[\Pi_2\big] = \frac{1}{b}\Big[\underbrace{\theta p_{_H} R_{H,2}}_{\text{Expected profit plums}} + \underbrace{(1-\theta)p_{_L} R_{L,2}}_{\text{Expected profit lemons}} - \bar{R}\Big]. \tag{10}$$

Solving the linear break-even condition $\theta(p_{_H} R_{H,2} - \bar{R}) \stackrel{!}{=} 0$ yields the interest rate offered to plums (11), while competition prevents efficient undercutting or the extraction of informational rents.

$$R_{H,2} = \begin{cases} \frac{\bar{R}}{p_H}, & \text{if } p_{_H} \geq \frac{\bar{R}}{R} \\ \text{no lending}, & \text{otherwise.} \end{cases} \tag{11}$$

Consistent with the approach for plums, we find the type-specific interest rate offered to lemons by solving the break-even condition $(1-\theta)(p_{_L} R_{L,2} - \bar{R}) \stackrel{!}{=} 0$ for $R_{L,2}$.

$$R_{L,2} = \begin{cases} \frac{\bar{R}}{p_L}, & \text{if } p_{_L} \geq \frac{\bar{R}}{R} \\ \text{no lending}, & \text{otherwise.} \end{cases} \tag{12}$$

Similar to imperfect information, lending at a rate better (i.e. lower) than $R_{H,2}$ or $R_{L,2}$ would allow a bank to win the competition for plums or lemons while serving them at a loss. Charging an interest rate higher than R (i.e. more than a project creates) on the other hand would push entrepreneurs out of the market, and thus no lending would occur at all. As a result banks earn 0 profits on both types.

4.1.3. Period 1 Interest Rates

In period 1, a new generation of entrepreneurs enters the market and engages in a business relationship with the banks for the first time. As a result, banks do not posses any knowledge about individual characteristics of entrepreneurs and and thus offer an uniform pooling rate to plums and lemons to compensate this lack of information. This leads to the following expected profits for period 1:

$$E\big[\Pi_1\big] = \frac{1}{b}\Big[\big(\theta p_{_H} + (1-\theta)p_{_L}\big)R_{P,1} - \bar{R}\Big]. \tag{13}$$

Again, competition erodes monopoly rents, enforces the 0 profits for all banks, and leads to

$$R_{P,1} = \begin{cases} \frac{\bar{R}}{\theta p_H + (1-\theta)p_L}, & \text{if } p_{_H} + p_{_L}\frac{(1-\theta)}{\theta} \geq \frac{\bar{R}}{\theta R} \\ \text{no lending}, & \text{otherwise,} \end{cases} \tag{14}$$

where the lower bounds for $p_{_H}$ and $p_{_L}$ formalize the bank's break-even thresholds for all combinations of entrepreneurial efforts (i.e. $p_{_i} \in [0,1],\ i \in \{H, L\}$). As indicated above, charging a rate higher than $R_{P,1}$ would allow competing banks to undercut profitably, while offering a rate below $R_{P,1}$ would create a loss on average. In addition, for lending to occur, the period 1 interest must not exceed the total return R entrepreneurs can extract from projects in the case of success. With respect to their funding, banks have to pay back their investors at the end of each period and roll over their funding. As a result, they have to break even in each period, and thus cannot take a loss in period 1 in order to win the competition for plums in period 2. Furthermore, period 1 interests between banks are equal in equilibrium, and thus banks share the market equally while making zero profits. More specifically, banks earn a profit on plums, which is offset by the loss incurred from lending to lemons.

Proposition 2. *In equilibrium, interest rates vary with the information available to the banks and rates under perfect information bracket less transparent regimes. In addition, banks can never charge more than the project return without risking a market collapse.*

$$\bar{R} \leq R_{H,2} \leq R_{P,2}(R) \leq R_{P,1} \leq R_{P,2}(0) \leq R_{L,2} \leq R$$

4.2. Entrepreneurial Perspective

In contrast to the assumption in section 4.1, entrepreneurial success is not exogenous but determined by the effort an individual entrepreneur invests in his or her project. As a result, effort choices arise endogenously and depend on the disutility a specific level of effort creates, the interest rates charged by the banks, and project returns. As a result, we characterize the equilibrium efforts of plums and lemons in this section and examine how the public transparency that comes with the use of a blockchain-based information system affects individual choices.

For our comparative analyses, we distinguish between the choices of uninformed and informed entrepreneurs given imperfect and perfect information: Uninformed entrepreneurs maximize their total utility without any information about their peers. This baseline setup represents the characteristics of an information system with a traditional access scope. Informed entrepreneurs on the other hand, can costlessly acquire information about the average success probabilities of plums and lemons from past generations. This setup formalizes the characteristics of a blockchain-based information system, which does not discriminate between users and disseminates (historic) information equally among banks, plums, and lemons. This knowledge allows entrepreneurs to mimic their respective counterparts in period 1 in order to change the banks' perception, and thus interest rates in period 2. Note that the ability to mimic does not depend on the presence of an information broker as entrepreneurs know their own type. Instead, they simply compute the average success probabilities from the default information of past generations to guide their behavior and set period 1 efforts. As a result, the potential behavioral changes are solely driven by the information system's access scope and not its informativeness.

In the following subsections, we derive the equilibrium effort levels and the resulting utility of individual entrepreneurs given imperfect and perfect information on the banking side and a limited and full access scope on the entrepreneurial side. In addition, we utilize comparative statics to investigate, how changing behavior in period 1 affects effort levels in period 2 and under which system configurations (information regimes / access scopes) utility improves. Figure 4 summarizes the underlying scenarios, highlights the level of information on each side of the market, and indicates the rationale for the following comparative analysis.

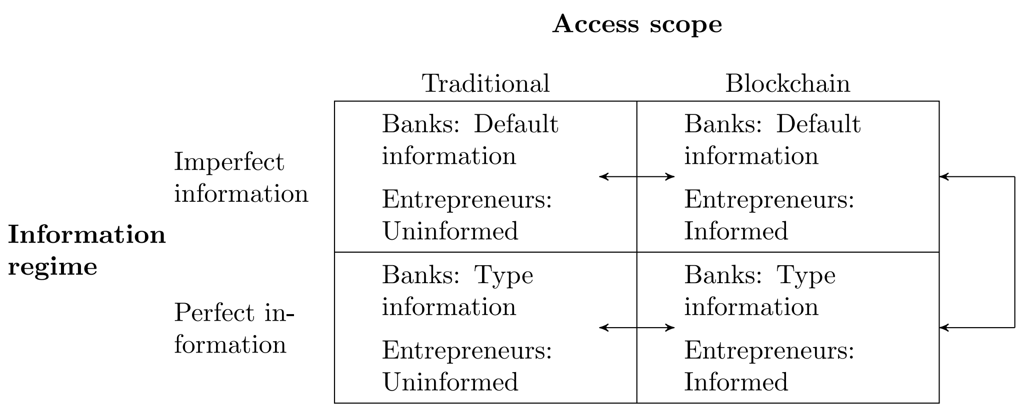


Fig. 4. **Information system configurations and analytic scenarios:** This matrix illustrates the scope of our comparative analysis and summarizes how the information regime and access scope vary with the system's configuration. Arrows indicate comparative analyses.

4.2.1. Uninformed Entrepreneurs

Effort choices under imperfect information. In the imperfect information regime, banks cannot distinguish between plums and lemons but try to approximate entrepreneurial quality based on the observed and shared default information from period 1. As a result, banks offer the pooling rates $R_{P,2}(0)$ and $R_{P,2}(R)$ conditional on period 1 project outcomes. Both, plums and lemons, incorporate this in their individual rationale and the utility over two periods is equal to equation (15), where $\Delta R = R_{P,2}(0) - R_{P,2}(R)$ represents the price improvement that results from project success in period 1.

$$\begin{aligned} U_i(p_{i,1}, p_{i,2}) =& \underbrace{p_{i,1}\left(R - R_{P,1}\right) - a_i p_{i,1}^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\left(R - E[R_{P,2}]\right) - a_i p_{i,2}^2}_{\text{Period 2 utility}} \\ =& p_{i,1}\left(R - R_{P,1}\right) - a_i p_{i,1}^2 + p_{i,2}\left(R + p_{i,1}\Delta R - R_{P,2}(0)\right) - a_i p_{i,2}^2. \end{aligned} \tag{15}$$

In addition, entrepreneurs do not posses any knowledge about the success probabilities of their peers. As a result, they have no means to guide behavioral changes and choose their efforts to maximize total utility. In consequence, deriving and solving the first order condition for period 1 and period 2 respectively yields the following effort choices:

$$p_{i,1}^U = \frac{R - R_{P,1} + \frac{\Delta R}{2a_i}\left(R - R_{P,2}(0)\right)}{2a_i - \frac{(\Delta R)^2}{2a_i}}, \qquad p_{i,2}^U = \frac{R + p_{i,1}\Delta R - R_{P,2}(0)}{2a_i}. \tag{16}$$

Note that $p_{i,t}^U$ takes the value of 1, if the prospect of high net returns in period 2 would push effort beyond 100% and the value of 0 if no lending occurs[11]. Figure 5 picks up the rationale of entrepreneurs outlined in equations (15) and (16) by illustrating marginal costs ($MC_{i,t}$), revenues ($MR_{i,t}$), and the resulting equilibrium effort levels of plums and lemons in periods 1 and 2[12]. It also highlights that plums always choose higher effort levels than lemons as success is cheaper for them. The magnitude of this difference depends on the quality difference $\Delta a > 0$ between both types. In addition, the prospect of a lower price in period 2 incentivizes entrepreneurs to invest more effort in period 1 than in period 2.

Proposition 3. *In the imperfect information equilibrium, uninformed plums always exert more effort than uninformed lemons and* $p_{H,t}^U > p_{L,t}^U \; \forall t \in \{1, 2\}$. *In addition, both types decrease effort levels in period 2 and* $p_{i,1}^U > p_{i,2}^U \; \forall i \in \{H, L\}$.

[11] No lending occurs in cases, whenever $p_{i,t}^U$ is too low to allow the banks to break even.

[12] The linearity of marginal costs and revenues, and thus the uniqueness of equilibria arises from the quadratic nature of the disutility of effort chosen for this study. Note that more cost functions with a higher degree or other functional forms may lead to multiple equilibria. However, we are confident that for this initial study a simple cost function suffices and leave more complex model setups with more complex or more general functional forms to future research.

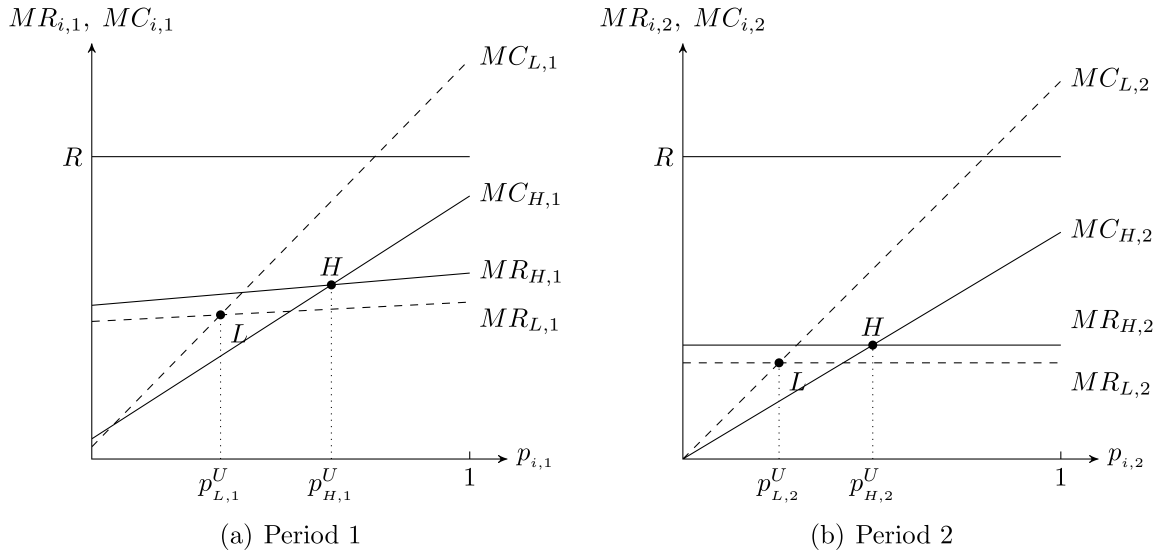


Fig. 5. **Effort choices of uninformed entrepreneurs under imperfect information:** The loci $MR_{i,t}$ depict the marginal return to effort for each type $i \in \{H, L\}$ and period $t \in \{1, 2\}$. Similarly $MC_{i,t}$ illustrates the type- and time-specific marginal disutility (i.e. cost) of effort. Solid lines represent plums and dashed lines lemons. The intersection points H and L define equilibria for plums and lemons, respectively. The horizontal line at R represents the social return to effort in each period.

Effort choices under perfect information. In the perfect information regime, an information broker evaluates period 1 performance of entrepreneurs and thereby allows banks to separate plums and lemons and offer type-specific interest rates to them. In consequence, their behavior in period 1 qualifies entrepreneurs to lend at either $R_{H,2}$ or $R_{L,2} \geq R_{H,2}$ in period 2 and total utility is equal to

$$U_i\big(p_{i,1}, p_{i,2}\big) = \underbrace{p_{i,1}\big(R - R_{P,1}\big) - a_i p_{i,1}^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\big(R - R_{i,2}\big) - a_i p_{i,2}^2}_{\text{Period 2 utility}}. \tag{17}$$

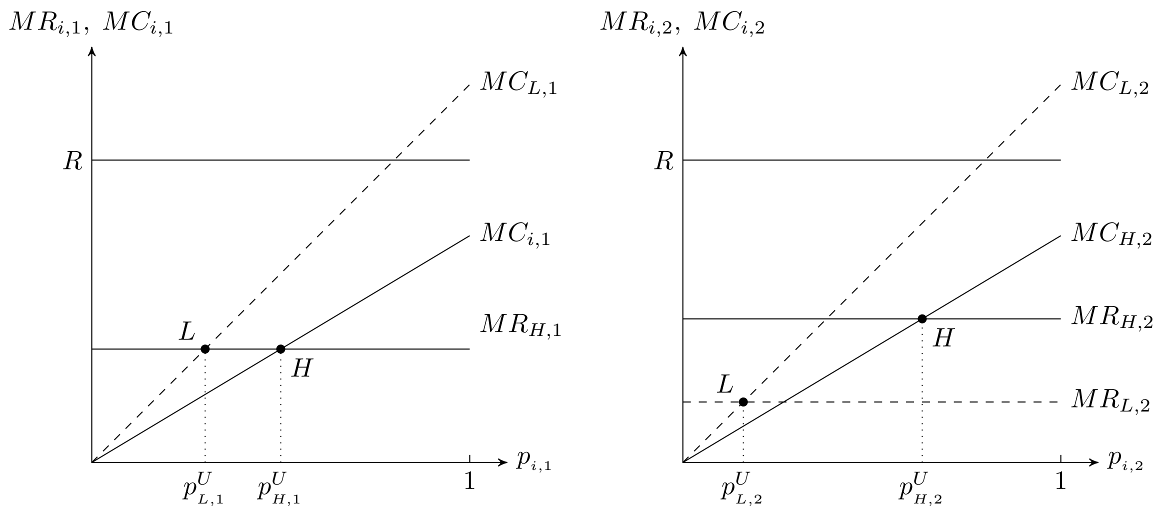
However, without access to the information system entrepreneurs do not have any information how to behave in period 1, in order to qualify for a lower rate. In consequence, they anticipate interest rates offered in period 2 correctly and in compliance with their type and maximize total utility accordingly. Similar to the imperfect information regime, deriving the resulting first order conditions for both periods and solving them for $p_{i,1}$ and $p_{i,2}$ respectively yields the equilibrium choices for plums and lemons:

$$p^U_{i,1} = \frac{R - R_{P,1}}{2a_i} \qquad p^U_{i,2} = \frac{R - R_{i,2}}{2a_i} \tag{18}$$

Again, $p^U_{i,t}$ assumes the value of 0 without lending and 1 if net returns are too high.

Figure 6 illustrates the equilibrium effort choices of plums and lemons in periods 1 and 2 and highlights differences between types and changes between periods. While entrepreneurs are pooled in period 1, the separating equilibrium in period 2 enhances the impact of quality differences between types and induces plums to increase and lemons to lower their effort in period 2. More specifically, offering discriminatory interest rates disables the stochastic price effect and thereby prevents entrepreneurs from indirectly profiting from higher efforts in period 1.

Proposition 4. *Under perfect information, plums always exert greater equilibrium effort than lemons and* $p^U_{H,t} > p^U_{L,t}$ $\forall t \in \{1, 2\}$. *In addition, the separation in period 2 prevents plums from decreasing* ($p^U_{H,2} \geq p^U_{H,1}$) *and lemons from increasing* ($p^U_{H,2} \leq p^U_{H,1}$) *effort levels.*



(a) Period 1 (b) Period 2

Fig. 6. **Effort choices of uninformed entrepreneurs under perfect information:** The loci $MR_{i,t}$ depict the marginal return to effort for each type $i \in \{H, L\}$ and period $t \in \{1, 2\}$. Similarly $MC_{i,t}$ illustrates the type- and time-specific marginal disutility (i.e. cost) of effort. Solid lines represent plums and dashed lines lemons. The intersection points H and L define equilibria for plums and lemons, respectively. The horizontal line at R represents the social return to effort in each period.

4.2.2. Informed Entrepreneurs

In contrast to uninformed entrepreneurs, informed plums and lemons have access to information about the average success probabilities of previous generations stored in the historic record of the blockchain-based information system. This information allows them to direct their behavior in period 1 and mimic the respective other type $-i$ in order to deceive the bank they are lending from. Formally, we implement this notion by setting period 1 effort levels of informed entrepreneurs to period 1 choices of the respective other type from the uninformed scenario. This way a lemon can look like a plum at the end of period 1 and vice versa.

To investigate whether such behavior occurs, we examine its potential impact on utility in period 1 ($\Delta U_{i,1}$) and period 2 ($\Delta U_{i,2}$). In period 1, mimicking always creates a utility loss, because it requires a shift away from the optimal choices identified in section 4.2.1. In consequence, period 2 gains have to outweigh this period 1 loss for a given set of effort choices $(p_{i,1}, p_{i,2})$ to make mimicking profitable. Eventually, the total change in utility $\Delta U_i = \sum_{t\in\{1,2\}} \Delta U_{i,t}$ quantifies this net impact of mimicking over time. If total utility increases, mimicking is a dominant strategy. In addition to the motivation to mimic, we dismantle utility effects into their components and identify changes in the realized return to effort, the related cost, and period 2 prices as effect channels.

Recall that the ability to mimic does not depend on the information regime. However, perfect and imperfect information still affect the banking equilibrium (i.e. interest rates), and thus indirectly affect mimicking. Also note that setting period 1 efforts to fixed value limits the choice of entrepreneurs to the effort exerted in period 2. To find these period 2 choices, we apply the first order condition to entrepreneurial utility and solve it for $p_{i,2}$.

Effort choices under imperfect information. Under imperfect information, banks have to rely on default information to approximate the characteristics of plums and lemons. As a result, they offer the pooling rates $R_{P,2}(0)$ and $R_{P,2}(R)$ conditional on period 1 project outcomes. From an entrepreneurial perspective, the uncertainty on the banking side creates a stochastic price effect ΔP that translates the impact of behavioral changes from period 1 to period 2. Consequently, utility over two periods is equal to

$$\begin{aligned} U_i(p^U_{-i,1}, p_{i,2}) &= \underbrace{p^U_{-i,1}\big(R - R_{P,1}\big) - a_i(p^U_{-i,1})^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\big(R - E[R_{P,2}]\big) - a_i p^2_{i,2}}_{\text{Period 2 utility}} \\ &= p^U_{-i,1}\big(R - R_{P,1}\big) - a_i(p^U_{-i,1})^2 + p_{i,2}\big(R + \underbrace{p^U_{-i,1}\Delta R}_{\Delta P} - R_{P,2}(0)\big) - a_i p^2_{i,2}. \end{aligned} \tag{19}$$

In addition, access to the information system supplies them with behavioral information about plums and lemons and thereby enables mimicking in period 1 by setting period 1 efforts to $p^I_{i,1} := p^U_{-i,1}$. Solving the resulting first order condition with fixed period 1 efforts yields the period effort choices of mimicking entrepreneurs (20).

$$p^I_{i,2}(p^U_{-i,1}) = \frac{R + p^U_{-i,1}\Delta R - R_{P,2}(0)}{2a_i} \tag{20}$$

Again, $p^I_{i,2}$ takes the value 0 without lending and is capped at 1. In period 1, the imbalance between the realized return and the corresponding costs, created by changing efforts, pushes entrepreneurs out of their equilibrium as $MR_{i,1}(p^U_{-i,1}) \neq MC_{i,1}(p^U_{-i,1})$. Moreover, changing period 1 efforts shifts entrepreneurs to a new equilibrium period 2, where realized returns and costs change according to the new effort choice $p^I_{i,2}(p^U_{-i,1})$. However, this new equilibrium is still affected by the behavioral change in period 1, as the inter-temporal stochastic price effect indirectly translates the direction and strength of effort changes to period 2. In conjunction with proposition 3 this indicates that plums continue to lower their effort levels in period 2 after behaving like lemons in period 1. The same logic applies to lemons but with an inverse direction as they raise their efforts to mimic plums.

Proposition 5. *When entrepreneurs commit to mimicking under imperfect information and set $p^I_{i,1} := p^U_{-i,1}$, they are locked-in to exert inefficiently low (plums) or high (lemons) effort levels $p^I_{H,2} < p^U_{H,2}$ and $p^I_{L,2} > p^U_{L,2}$ in period 2 as well.*

To examine the impact on utility, we take a closer look at utility changes in periods 1 and 2. For plums, utility in period 1 decreases as the deviation from equilibrium effort to $p^I_{H,1} = p^U_{L,1} < p^U_{H,1}$ (prop. 3) creates an imbalance between marginal costs and returns $MR_{i,1}(p^U_{-i,1}) < MC_{i,1}(p^U_{-i,1})$. As a result, the positive cost effect that comes with lower efforts cannot offset the associated negative return effect. In period 2, plums are furthermore locked-in to their inefficient behavior in period 1 via the price effect and the utility loss spills over to period 2 ($\Delta U_{H,2} < 0$). In total, the utility losses in periods 1 and 2 sum up to $\Delta U_H < 0$ and indicate that mimicking does not provide any benefits to plums.

For lemons, the analysis is a bit more complex: While deviation from equilibrium also leads to utility losses $\Delta U_{L,1} < 0$ in period 1[13], increasing efforts $p^I_{L,2} > p^U_{L,2}$ shifts them to a lower expected interest rate in period 2 (proposition 5). Moreover, the costs for reaching this new equilibrium are borne in period 1, and a utility gain $\Delta U_{L,2} > 0$ occurs in period 2. More specifically, the price effect outweighs the increasing costs associated with higher efforts. However, in total these gains cannot outweigh the loss in period 1, and thus the net utility change $\Delta U_L = \Delta U^U_{L,1} + \Delta U^U_{L,2}$ remains negative as period 1 costs dominate. In consequence, lemons do not profit from changing their behavior in period 1 either.

Proposition 6. *Mimicking does not constitute a dominant strategy under imperfect information as it leads to equilibria with inferior utility $U_i\big(p^U_{-i,1}, p^I_{i,2}\big) < U_i\big(p^U_{i,1}, p^U_{i,2}\big)$ $\forall i \in \{H, L\}$.*

As result, proposition 6 indicates that the introduction of a blockchain-based information system does not induce entrepreneurs to deviate from their equilibrium efforts without the

[13] In contrast to plums, the increasing efforts of lemons lead to inefficient high productivity levels, where $MR_{i,1}(p^U_{-i,1}) > MC_{i,1}(p^U_{-i,1})$.

analytic service of an information broker. Moreover, if they would exhibit deceptive behavior in period 1 they are locked-in to their inefficient choice and their utility would decrease even further. Figure 7 illustrates the behavioral changes of plums and lemons in period 1, their impact on period 2 efforts, the related trade-offs, and the utility gains and losses in an exemplary manner.

Effort choices under perfect information. Under perfect information, the banks can distinguish between plums and lemons and are able to offer type-specific interest rates $R_{H,2} \leq R_{L,2}$ in period 2. As a result, behavioral changes in period 1 create a deterministic price effect ΔP in period 2 and total utility is equal to:

$$U_i\left(p^U_{-i,1}, p_{i,2}\right) = \underbrace{p^U_{-i,1}\left(R - R_{P,1}\right) - a_i\left(p^U_{-i,1}\right)^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\overbrace{\left(R - R_{-i,2}\right)}^{\Delta P} - a_i p^2_{i,2}}_{\text{Period 2 utility}} \tag{21}$$

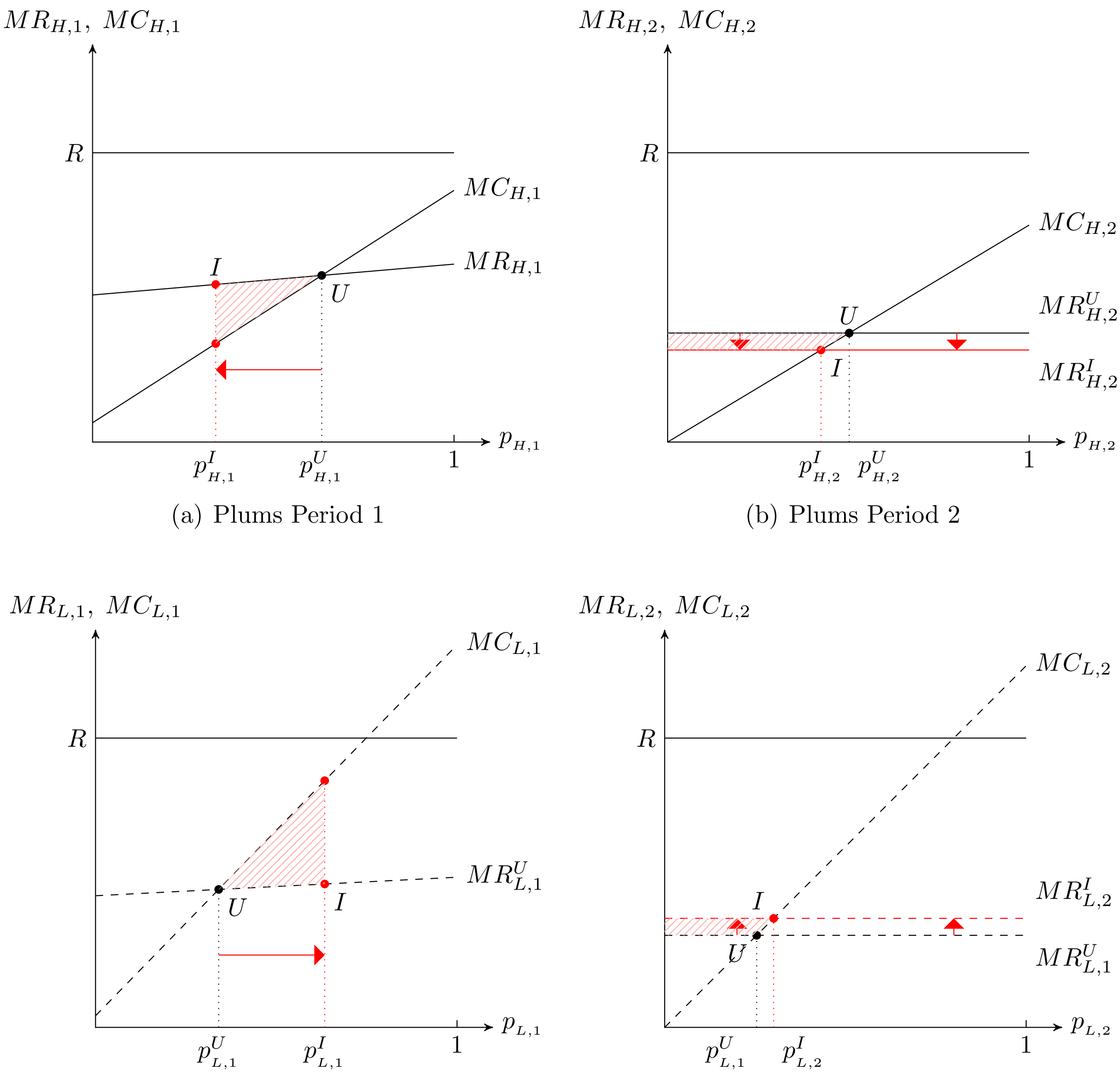
Moreover, the extended access scope of the information system enables plums to learn about the average success probabilities of their respective counterparts and eventually mimic them. In consequence, fixing period 1 efforts to $p^I_{i,1} := p^U_{-i,1}$ and solving the resulting first order condition for $p_{i,2}$ yields the period 2 choices mimicking entrepreneurs (22).

$$p^I_{i,2} = \frac{R - R_{-i,2}}{2a_i} \tag{22}$$

Like before, $p^I_{i,2}$ takes the value of 0 without lending and cannot be higher than 1. However, the deviation from the uninformed equilibrium in period 1 creates an imbalance between returns and costs as $MR_{i,1}(p^U_{-i,1}) \neq MC_{i,1}(p^U_{-i,1})$ and leads to new period 2 equilibria for both types. In these equilibria banks charge either $R_{H,2}$ or $R_{L,2}$ to entrepreneurs who pretended to be plums or lemons in period 1. As a result, decreasing period 1 efforts to $p^U_{L,1}$ crushes (plums') and increasing period 1 efforts to $p^U_{H,1}$ boosts (lemons') net returns in period 2. Similar to the imperfect information regime, this indicates that mimicking in period 1 is followed by a behavioral change with the same direction in period 2.

Proposition 7. *Consistent with the imperfect information regime, entrepreneurs who commit to mimicking under perfect information and set $p^I_{i,1} := p^U_{-i,1}$, are locked-in to their behavior and furthermore decrease (plums) or increase (lemons) period 2 effort. In consequence, $p^I_{H,2} < p^U_{H,2}$ and $p^I_{L,2} > p^U_{L,2}$.*

From a utility perspective, plums still experience a utility loss $\Delta U_{H,1} < 0$ when they lower period 1 effort to an inefficiently low return level $MR_{i,1}(p^U_{-i,1}) < MC_{i,1}(p^U_{-i,1})$. The same holds



(a) Plums Period 1

(b) Plums Period 2

(c) Lemons Period 1

(d) Lemons Period 2

Fig. 7. **Effort choices of informed entrepreneurs under imperfect information:** The loci $MR_{i,t}$ depict the marginal return to effort for each type $i \in \{H, L\}$, period $t \in \{1, 2\}$. Similarly $MC_{i,t}$ illustrates the type- and time-specific marginal disutility (cost) of effort. Solid lines represent plums and dashed lines lemons. If marginal returns of costs change with the information regime we indicate this difference with U for uninformed and I for informed entrepreneurs. Otherwise, no indication is given. Behavioral changes that come with the blockchain regime in period 1 and the resulting impact in period 2 are marked in red. More specifically, the utility changes $\Delta U^j_{i,t}$ of plums and lemons are illustrated by a filling with a red pattern, while red arrows indicate the direction of changes and corresponding effects. In period 1, the intersection point U defines the equilibrium before blockchain usage, whereas I represents the adjusted behavior of mimicking entrepreneurs. Similarly, in period 2 U highlights the equilibrium efforts before blockchain usage and I the equilibrium outcomes that result from deceptive behavior in period 1. The horizontal line at R represents the social return to effort in each period.

true in period 2, where the inefficient behavior from period 1 spills over to period 2 via an increased interest rate $R_{L,2} \leq R_{H,2}$ and creates an additional utility loss $\Delta U_{H,2} < 0$. In total, this finding is consistent with the prediction for imperfect information and highlights that plums are not able to derive any utility gains from mimicking - independent of the information regime.

Proposition 8. *Under perfect information, mimicking does not constitute a dominant strategy for plums as it leads to equilibria with inferior utility* $U_H\big(p^I_{H,1}, p^I_{H,2}\big) < U_H\big(p^U_{H,1}, p^U_{H,2}\big)$.

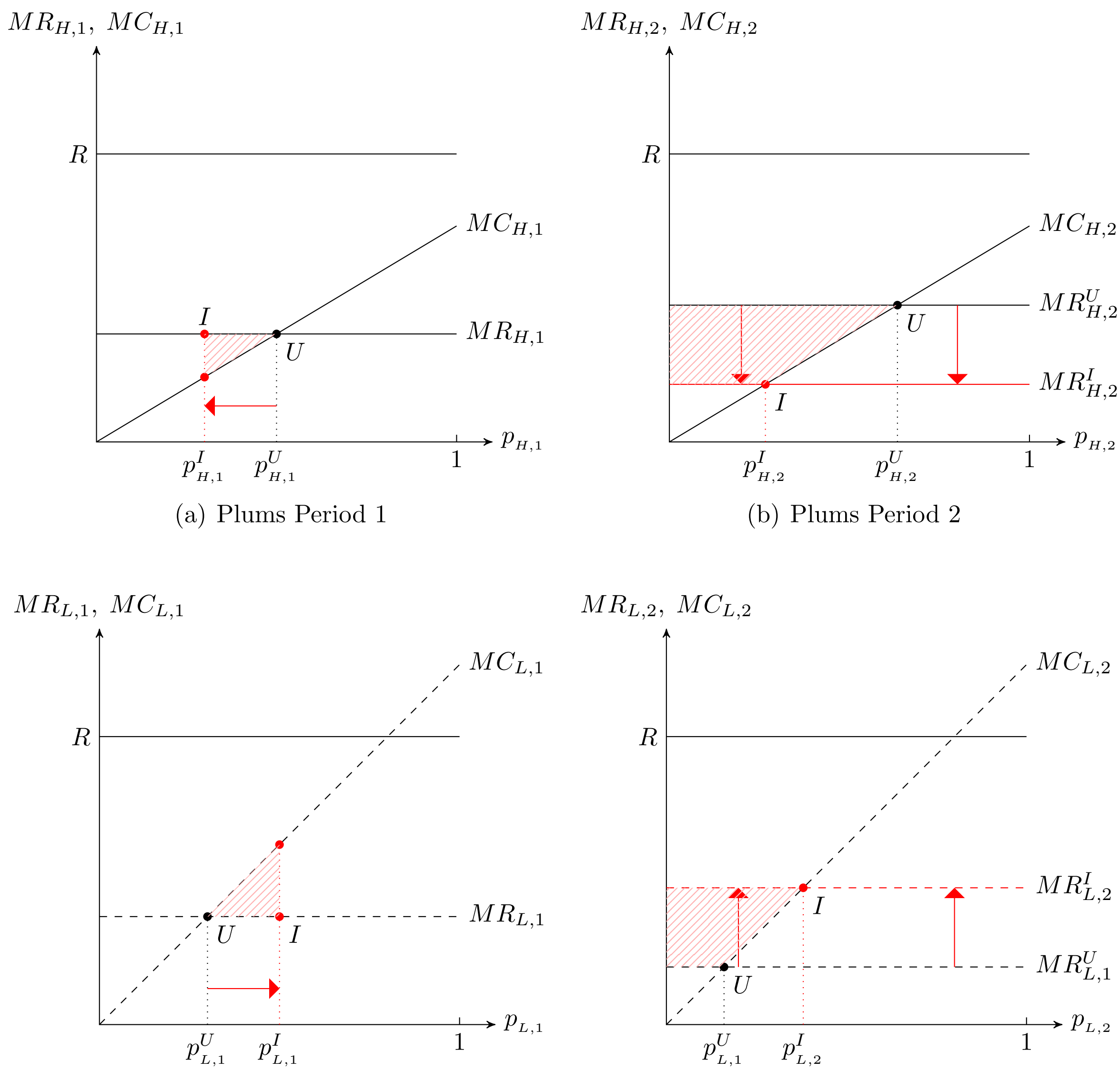
Similar to plums, lemons also make a suboptimal choice in period 1 ($MR_{L,1}(p^U_{H,1}) > MC_{L,1}(p^U_{H,1})$) and loose utility as a result ($\Delta U_{L,1} < 0$). However, deterministic nature of the inter-temporal price effect allows them to maximize their gains from mimicking. More specifically, in combination with the resulting return effect, the price effect outweighs the costs associated with higher efforts and creates a utility gain in period 2 ($\Delta U_{L,2} > 0$). Eventually, the utility gains in period 2 are strong enough to offset the costs of mimicking from period 1 and total utility increases $\Delta U_L > 0$.

Proposition 9. *In contrast to plums, the historic performance information disclosed by a blockchain-based system enables informed lemons to reach a new equilibrium with* $U_L\big(p^I_{L,1}, p^I_{H,2}\big) > U_L\big(p^U_{L,1}, p^U_{L,2}\big)$. *In consequence, mimicking is a dominant strategy under imperfect information.*

Moreover, the resulting net utility gain depends on the difference between the relative interest rate improvement (relative price effect) and the increase in the disutility of effort it entails (relative cost effect).

$$\Delta U_L = \underbrace{\frac{(R - R_{P,1})^2}{4a_L}\left(\underbrace{\frac{(R_{L,2} - R_{H,2})(2R - R_{H,2} - R_{L,2})}{(R - R_{P,1})^2}}_{\text{Relative price effect}} - \underbrace{\frac{(a_L - a_H)^2}{a_H^2}}_{\text{Relative cost effect}}\right)}_{\text{Net utility gain}} > 0 \tag{23}$$

In total, this indicates that the introduction of a blockchain-based information systems only induces lemons to mimic plums if banks can be deceived (i.e. when they have type information). Plums on the other hand, do not experience any benefits from additional information. In addition, mimicking entrepreneurs are locked-in to their inefficient choice - irrespective of their type. Figure 8 summarizes these findings and illustrates the behavioral changes of plums and lemons in period 1, their impact on period 2 efforts, and indicates the utility gains and losses incurred in both periods.



(a) Plums Period 1 (b) Plums Period 2

(c) Lemons Period 1 (d) Lemons Period 2

Fig. 8. **Effort choices of informed entrepreneurs under perfect information:** The loci $MR_{i,t}$ depict the marginal return to effort for each type $i \in \{H, L\}$, period $t \in \{1, 2\}$. Similarly $MC_{i,t}$ illustrates the type- and time-specific marginal disutility (cost) of effort. Solid lines represent plums and dashed lines lemons. If marginal returns of costs change with the information regime we indicate this difference with U for uninformed and I for informed entrepreneurs. Otherwise, no indication is given. Behavioral changes that come with the blockchain regime in period 1 and the resulting impact in period 2 are marked in red. More specifically, the utility changes $\Delta U^j_{i,t}$ of plums and lemons are illustrated by a filling with a red pattern, while red arrows indicate the direction of changes and corresponding effects. In period 1, the intersection point U defines the equilibrium before blockchain usage, whereas I represents the adjusted behavior of mimicking entrepreneurs. Similarly, in period 2 U highlights the equilibrium efforts before blockchain usage and I the equilibrium outcomes that result from deceptive behavior in period 1. The horizontal line at R represents the social return to effort in each period.

4.3. Market Perspective

Section 4.2 highlights that entrepreneurs - or more specifically lemons - only have an incentive to mimic their counterparts when banks can observe type information. Plums on the other hand have no incentive to do so, irrespective of the information regime. In consequence, we focus on the perfect information regime in our welfare analysis. Moreover, we set the interest rates offered and consequently charged by banks as exogenously given, while their order is defined by proposition 2. This ensures the validity of our comparative analysis and formalizes the notion that banks use the information from past generations to determine the interest rates offered to the current one. In addition, banks act as mediators between the capital market and entrepreneurs, and thus do not generate welfare directly. Taking these considerations into account, we define total welfare as the aggregate utility (Lange, 1942) of all mimicking lemons and unmodified plums:

$$\begin{aligned} W(p^U_{H,1}, p^U_{H,2}, p^I_{L,1}, p^I_{L,2}) = & \underbrace{\theta\big[\underbrace{p^U_{H,1}R - \bar{R} - V_H(p^U_{H,1})}_{\text{Period 1}} + \underbrace{p^U_{H,2}R - \bar{R} - V_H(p^U_{H,2})}_{\text{Period 2}}\big]}_{\text{Welfare from plums}} \\ & + \underbrace{(1-\theta)\big[\underbrace{p^I_{L,1}R - \bar{R} - V_L(p^I_{L,1})}_{\text{Period 1}} + \underbrace{p^I_{L,2}R - \bar{R} - V_L(p^I_{L,2})}_{\text{Period 2}}\big]}_{\text{Welfare from lemons}} \end{aligned} \tag{24}$$

To evaluate the welfare effects of blockchain adoption, we compare equation (24) with the welfare generated by uninformed plums and lemons while holding the information regime fixed (perfect information). The resulting welfare change ΔW is defined as the difference between the informed scenario outlined above and total welfare with completely uninformed entrepreneurs.

$$\Delta W = W(p^U_{H,1}, p^U_{H,2}, p^I_{L,1}, p^I_{L,2}) - W(p^U_{H,1}, p^U_{H,2}, p^U_{L,1}, p^U_{L,2}) = (1-\theta)\Delta U_L \tag{25}$$

Eventually, ΔW depends on the share of lemons in the market $(1-\theta)$ and is driven by the utility gains they experience from mimicking (23). The utility of plums does not affect welfare, because they do not change their behavior. In addition, there is no welfare effect on the banking side, as banks earn zero profits in their role as mediators and their costs of capital are constant and equal to $\bar{R}$.

Proposition 10. *Driven by the utility gains of mimicking lemons, the introduction of a blockchain-based information system increases the total welfare of our economy as* $\Delta W > 0$.

However, this entrepreneurial perspective on welfare does not consider the special role of banks and how they are affected by the behavioral changes of informed lemons. As mediators between the capital market and entrepreneurs, they manage entrepreneurial risks and transform denomination to allocate funds to plums and lemons efficiently in each period. To do so, they assess entrepreneurial quality, pool and separate risk accordingly, and offer credit conditional on their assessment, while perfect competition enforces the zero profit constraint. In consequence, they build their assessment on the historic information acquired from the information system and offer risk-adjusted interest rates to break-even given the average success probabilities learned from past generations. In the current generation, however, the introduction of a blockchain-based information system supplies entrepreneurs with additional information about their counterparts and thereby induces lemons to change their behavior. As a result, the actual effort levels exerted in period 1 and 2 do not comply with the break-even conditions $E[\Pi_1] \overset{!}{=} 0$ and $E[\Pi_2] \overset{!}{=} 0$ anymore. In the period 1 pooling equilibrium this is not harmful as efforts of lemons increase ($p^I_{L,1} > p^U_{L,2}$) and thus the realized profit $\Pi^I_1 > 0$. In period 2 however, the realized profit $\Pi^U_2 < 0$ as mimicking lemons wrongfully qualify for $R_{H,2}$ and the quality difference $\Delta a > 0$ prevents risk-adequate effort levels.

Proposition 11. *While the behavioral change of lemons improves welfare for the current generation, it also hurts the zero-profit constraint of the lending banks in period 2 as $p^U_{H,2} > p^I_{L,2}$. As result banks are not able to roll over funding at the end of period 2, go bankrupt, and future generations of entrepreneurs are cut off the capital market.*

Note that in all other scenarios, the introduction of a blockchain-based information system does not affect welfare as there is no incentive for rational agents to adapt their behavior given additional quality information. However, when entrepreneurs are prone to irrational behavior - as it is often the case in retail markets[14] - deviation from the uniformed equilibrium can harm welfare significantly ceteris paribus. For mimicking plums this is always the case, because they have to lower effort levels in period 1 to mimic lemons (proposition 3 and 4) and the resulting lock-in effects (proposition 5 and 7) push them to equilibria with lower utility in both periods (proposition 6 and 8). In addition, banks are not able to break even on them anymore, go bankrupt at the end of period 1, and the market collapses. Lemons on the other hand always experience a utility gain in period 2, because they receive a better price when mimicking plums in period 1. Under imperfect information however, this gain does not outweigh the costs of mimicking created in period 1 and total utility decreases (proposition

[14] There is a multitude of studies that show the existence of irrational behavior empirically (Poteshman and Serbin, Poteshman and Serbin; Shapira and Venezia, 2001) and analyze the underlying biases and effects (Patel, Zeckhauser, and Hendricks, 1991; Subrahmanyam, 2007).

6). While raising effort levels in period 1 is beneficial for banks, the same rationale as in proposition 11 drives them into banruptcy in period 2. Possible reasons for irrational behavior include the misinterpretation (i.e. wrong assessment) of historic data, the limited ability of entrepreneurs to access and process the information from the blockchain-based information system, or simply flawed strategic rationales.

5. Discussion

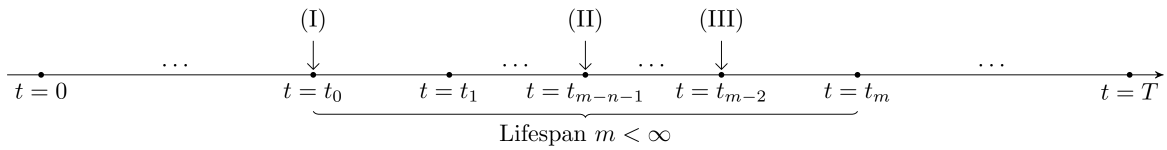
However, the analysis in section 4 does not consider long term effects that may arise with a longer lifespan of individual generations or overlapping generations. Figure 9 illustrates these model variations and forms a foundation for the following discussion of related effects.

In the case of a longer lifespan, generations live for $2 < m < \infty$ periods instead of two. As a result, lemons can choose to change their behavior and mimic plums at the beginning of each period. Figure 9(a) illustrates a generation with a m period lifespan and highlights potential timings for opportunistic behavior. If they decide to mimic before the first period, they can improve loan conditions in period 2 but cut themselves off the capital market for all subsequent periods (I). A behavioral change before some intermediate period $m-n-1$ where $2 < n < m$ creates a positive utility in each period including $m-n-1$ and an additional utility improvement in period $m-n$ (II). However, as a a result of the market collapse at the end of period $m-n$, entrepreneurs are not able to implement any more projects and utility is equal to zero for the rest of their life. If lemons deceive banks in penultimate period $m-2$, they can fund and implement a project in each period and increase their utility in the last period (III). In addition, they are not affected by the market collapse at the end of period m and the following generations have to suffer the consequences. Equation (26) summarizes the total utility generated in each case (I - III). Moreover, from $t_2 < t_{m-n-1} < t_m$ directly follows that betraying in the penultimate period $m-2$ is the best strategy to maximize utility, if we assume that interest rates are constant over time.

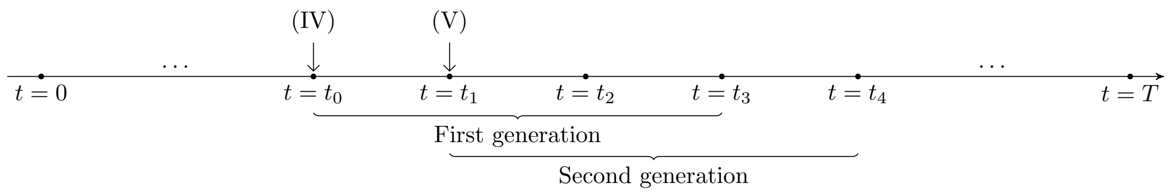
$$\underbrace{\sum_{t=t_1}^{t_2} U_{L,t} + \Delta U_L}_{\text{(I)}} < \underbrace{\sum_{t=t_1}^{t_{m-n-1}} U_{L,t} + \Delta U_L}_{\text{(II)}} < \underbrace{\sum_{t=t_1}^{t_m} U_{L,t} + \Delta U_L}_{\text{(III)}} \tag{26}$$

Proposition 12. *If the lifespan of a generation increases to $m < \infty$, mimicking in the penultimate period $m-2$ is a dominant strategy for lemons.*

To discuss to effects of overlapping generations, we assume that each generation lives for three periods and a new generation arrives at the market in every period. Figure 9(b)



(a) Generations with a longer lifespan



(b) Overlapping generations

Fig. 9. **Model variations:** This figure illustrates the timelines of actions of opportunistic lemons with a lifespan of $m < \infty$ periods as well as lemons with overlapping generations. In addition, $2 < n < m$. Different cases of opportunistic behavior are highlighted with arrows and superscripts (I) to (V).

illustrates resulting population structure for two generations. Each generation has the chance to mimic the respective other type within their own generation in each period. However, according to 12, lemons do not mimic plums between $t = t_0$ and $t = t_1$ (IV). Instead, they increase their effort levels between t_1 and t_2 to extract the utility gain ΔU_L at the end of the third and last period of their life (V). As a result, the market collapses at $t = t_3$ and the second generation is not able to get funding for the third and last project. If the lemons of the second generation are aware of this behavioral pattern, it is optimal for them to deceive banks and mimic plums between t_1 and t_2 (i.e. the first period of their life) as well (V). The resulting utility is equal to $U_{L,t_2} + U_{L,t_3} + \Delta U_L$, which is greater than $U_{L,t_2} + U_{L,t_3}$. Note that this notion of overlapping generations does not consider interconnections between generations, such as ancestry or heritage. In addition, we do not consider changing average success probabilities as a result of the behavioral changes of the first generation.

Proposition 13. *If entrepreneurial generations overlap each other, the first generation of lemons that reaches the last period of their life triggers a cascade of opportunistic behavior. As a result, all subsequent generations that still overlap with the first one will mimic in the same period.*

In addition, there are some other minor model variations and limitations, we will discuss briefly here. First, repeating the two-period lending game with an infinite number of generations does not affect our findings in the long run. The market collapses, when one generation of lemons decides to mimic plums and consequently all subsequent generations loose access to the capital market. It is also important to note that the first generation is not able to deceive, because there is no information to guide their behavioral change stored in the information system at $t = 0$. Second, in section 3 we assumed that neither banks nor entrepreneurs discount profits or utility. Introducing a positive discount rate on the entrepreneurial side would emphasize the timing of utility changes as today's utility becomes more valuable than tomorrow's. In consequence, the costs of mimicking in period 1 would increase, while its gains in period 2, and thus ΔU_L would decrease. Third, relaxing competition in the banking sector - for instance via relationship information - would allow banks to extract rents from an informational monopoly, and thereby increase their ability to compensate violations of their break-even condition. Similarly, a risk averse banking sector would incorporate a safety cushion in the break-even condition, and thus become more robust towards opportunistic behavior. Finally, good entrepreneurs do not drop out of the market, because they remain unaffected by the behavior of lemons and always experience positive utility when implementing a project - if their effort levels are high enough to get a funding. In a dynamic world however, this may change as banks adapt their behavior to the take the consequences of misbehaving lemons into account.

6. Conclusion

In total, the analyses in section 4 and the extensions discussed in section 5 help us to derive several lessons for blockchain ventures in research and practice. First and foremost, they relate to research question 1 and indicate that the public disclosure of quality information can give rise to opportunistic behavior. More specifically, we find that lemons can increase their utility by behaving opportunistically, when information brokers, such as credit bureaus or rating agencies, enhance the informativeness of the stored and shared data. In such market environments, increasing period 1 efforts gives lemons access to better prices in period 2. To determine which effort levels qualify them as plums, they use the information from the blockchain's public record to learn about the average quality of plums and lemons and adapt their behavior accordingly. The resulting utility gain is more pronounced for greater price improvements, lower quality differences, and lower quality in general. In contrast, we do not find any incentives for plums to behave opportunistically. Moreover, their decreasing utility over both periods is in line with prior research such as Padilla and Pagano (2000) and outlines the disciplinary effect increasing transparency can have. In opaque market environments, banks pool plums and lemons conditional in period 1 project outcomes and neither plums nor lemons have an incentive to behave opportunistically.

Irrespective of the information regime, we furthermore observe lock-in effects across all analytic scenarios and entrepreneurial types. As a result, plums (lemons) who lower (increase) their efforts in the first period will do the same in the subsequent one. The severity of this effect is driven by the transparency of a market as well as price and quality differences and reinforces the consequences of opportunistic behavior in period 1. While extraneous for rational agents, erroneous decisions made by irrational agents can spill over to period 2 and harm utility permanently as entrepreneurs are committed to their inefficient choice from period 1.

From the market perspective taken in research question 2, the opportunistic behavior of lemons creates a welfare gain within their own generation. The strength of this gain depends on the share of lemons in the market $(1-\theta)$ and is driven by the utility gains of mimicking lemons. However, the resulting unjustified access to better loan conditions harms the break-even condition of banks and prevents them from breaking even. As a result, the banks are not able to roll over funding, the supply side of the market collapses, and future generations are cut off from funding. In all other scenarios, the combination of irrational behavior of either plums or lemons or both and the following lock-in effects would harm welfare through a negative utility effect, while the market still collapses.

Eventually, the findings hold across various model variations, while generations with a longer lifespan experience an endgame effect and opportunistic behavior cascades through overlapping generations. In addition, we are confident that they hold implications that go beyond the market for credit and apply to other lemon markets, such as the used car or the insurance market, as well.

With respect to research question 3 these findings furthermore indicate that blockchain adoption can lead to market collapses in markets with a high level of transparency and intense competition. To mitigate these issues, blockchain designers could refrain from using smart contracts to implement value-adding services and analytic applications on the infrastructure level. In addition, using blockchain-based systems in environments prone to irrational behavior - such as retail markets - can harm welfare and impede a market's functioning permanently.

In aggregate, we contribute to three research streams: First, we contribute to the growing body of literature on the economics of blockchain by shedding light on the impact of the blockchain's public transparency paradigm on behavioral patterns in markets exposed asymmetric information. Second, we contribute to the field of banking research by examining the effect of the disclosure of quality information to the broad public. As a result, our findings hold implications for the design of information sharing arrangements as well the shaping of transparency regulations such as the Payment services directive of the European Union. Third, we contribute to the body of blockchain adoption literature by highlighting the risks of market-oriented application contexts. However, there are also various potential model extensions that go beyond the scope of this initial study. First and foremost, we limit our analyses to comparative statics and believe that considering dynamic interactions between banks and entrepreneurs could add another interesting dimensions to our results. We also set the cost for information sharing and acquisition - and thus the information system itself - to zero for both sides of the market. While adding a constant cost factor on both sides of the market would simply shift interest rates to a higher and utility to a lower level, modelling the actual costs of a blockchain-based systems is more complex[15]. In addition, we do not consider switching costs, refrain form using a generalized functional form of the disutility of effort, and exclude evolution of wealth on the entrepreneurial side and the role relationship information and opportunistic behavior on the banking side. These aspects are interesting and relevant extensions to consider in the context of public transparency and provide great opportunities for future research.

[15]An initial study that analyzes such a mechanism is Saleh (2018). However, there is a multitude of consensus mechanisms in the blockchain world that reach consensus on database updates and thus create costs in different ways.

Appendix A. Variable Definitions

A.1. Banks

Variable	Scope	Description
b	> 1	Number of competing banks
$\bar{R}$	$[1, R]$	Gross interest rate banks pay to raise funds
Π_t	-	Individual bank profits in period t
$R_{j,t}$	$[\bar{R}, R]$	Interest rate offered to entrepreneurs
t	{1,2}	Lending period
j	{H,L,P}	Equilibrium characteristics (P = pooling, H, P = separating)
$R_{P,1}$	$[\bar{R}, R]$	Period 1 pooling rate
$R_{H,2}$	$[\bar{R}, R]$	Period 2 interest rate offered to plums
$R_{L,2}$	$[\bar{R}, R]$	Period 2 interest rate offered to lemons
$R_{P,2}(0)$	$[\bar{R}, R]$	Period 2 pooling rate offered following default in period 1
$R_{P,2}(R)$	$[\bar{R}, R]$	Period 2 pooling rate offered following success in period 1
$\mu(H\|R)$	$[0, 1]$	Probability that a successful entrepreneur is a plum
$\mu(L\|R)$	$[0, 1]$	Probability that a successful entrepreneur is a lemon
$\mu(H\|0)$	$[0, 1]$	Probability that a defaulted entrepreneur is a plum
$\mu(L\|0)$	$[0, 1]$	Probability that a defaulted entrepreneur is a lemon

A.2. Entrepreneurs

Variable	Scope	Description
R	> 1	Project return in the case of success
i	H, L	Entrepreneurial type
H	-	Good entrepreneur (plum)
L	-	Bad entrepreneur (lemon)
θ	$(0, 1)$	Share of plums in the market
$1 - \theta$	$(0, 1)$	Share of lemons in the market
a_i	> 0	Entrepreneurial quality of type i
$p^k_{i,t}$	$[0, 1]$	Effort level (success probability) of a type i entrepreneur in period t
k	$\{U, I\}$	Level of entrepreneurial information
U	-	Uninformed entrepreneur
I	-	Uninformed entrepreneur
$V_i(p^k_{i,t})$	$a_i {p^k_{i,t}}^2$	Disutility of effort of a type i entrepreneur
$U_i(p^k_{i,1}, p^k_{i,2})$	> 0	Total utility of type i entrepreneurs
$MC^k_{i,t}$	-	Marginal costs of type i entrepreneurs in period t
$MR^k_{i,t}$	-	Marginal returns of type i entrepreneurs in period t

Appendix B. Proofs and Calculus

B.1. Proofs

Proposition 1: Banks' assessment of entrepreneurs

$$\underbrace{\underbrace{p_H}_{\text{Perfect info.}} \overset{?}{>} \underbrace{\mu(H|R)p_H + \mu(L|R)p_L}_{\text{Imperfect info.}}}_{\text{Period 2}} \overset{?}{>} \underbrace{\underbrace{\theta p_H + (1-\theta)p_L}_{\text{Full opacity}}}_{\text{Period 1}} \overset{?}{>} \underbrace{\underbrace{\mu(H|0)p_H + \mu(L|0)p_L}_{\text{Imperfect info.}} \overset{?}{>} \underbrace{p_L}_{\text{Perfect info.}}}_{\text{Period 2}}$$

While banks operate under full opacity in period 1, they acquire information about entrepreneurial characteristics before their second offer in period 2. However, their ability to distinguish between types depends on the features of the information system they acquire the information from. Under perfect information, their approximation of effort levels (i.e. success probabilities) is completely accurate. Under imperfect information on the other hand, banks underestimate (overestimate) the effort levels of plums (lemons). To show this, we compare the different information regimes and periods with each other.

To compare perfect with imperfect information, we have to consider the average effort levels of plums and non-defaulters and lemons and defaulters: For non-defaulters $p_H > \mu(H|R)p_H + \big(1 - \mu(H|R)\big)p_L$ holds true, if $\mu(H|R) < 1$ and $p_H > p_L$. While $p_H > p_L$ is trivially true by assumption, $\mu(H|R) = \frac{p_H \theta}{\theta p_H + (1-\theta)p_L} < 1$ is only true, if $\theta < 1$. However, $\theta < 1$ is also fulfilled by assumption as there is at least one lemon in the market. As a result, the first part of proposition 1 is true and $p_H > \mu(H|R)p_H + \big(1 - \mu(H|R)\big)p_L$ (I). The same logic applies to the comparison between defaulters and lemons. $\mu(H|0)p_H + \big(1 - \mu(L|0)\big)p_L > p_L$ holds, if $\mu(H|0) > 0$ and $p_H > p_L$. Again, both conditions are trivially fulfilled by assumption as there is at least one lemon in the market and effort is more costly to lemons. In consequence, the last part of proposition 1 proofs to be correct as well (II).

For imperfect information and full opacity, $\mu(H|R)p_H + \big(1 - \mu(H|R)\big)p_L > \theta p_H + (1-\theta)p_L$ is true, if $\mu(H|R) > \theta$ and $p_H > p_L$.

$$\mu(H|R) = \frac{p_H \theta}{\theta p_H + (1-\theta)p_L} > \theta \Leftrightarrow \frac{p_H}{\theta p_H + (1-\theta)p_L} > 1 \Leftrightarrow p_H > \theta p_H + (1-\theta)p_L$$

This is trivially true as $\theta \in (0,1)$ and $p_H > p_L$ and so is $\mu(H|R)p_H + \big(1 - \mu(H|R)\big)p_L < \theta p_H + (1-\theta)p_L$ (III). Analogously, $\theta p_H + (1-\theta)p_L > \mu(H|0)p_L + \big(1 - \mu(H|0)\big)$ follows from our assumption that $\theta \in (0,1)$ and $p_H > p_L$ (IV).

In total, this shows that when effort levels are positive and high enough to create lending, proposition 1 proofs to be true and

$$p_H \overset{(I)}{>} \mu(H|R)p_H + \mu(L|R)p_L \overset{(III)}{>} \theta p_H + (1-\theta)p_L \overset{(IV)}{>} \mu(H|0)p_H + \mu(L|0)p_L \overset{(II)}{>} p_L.$$

□

Proposition 2: Relationship between interest rates

$$\bar{R} \overset{?}{\leq} R_{H,2} \overset{?}{\leq} R_{P,2}(R) \overset{?}{\leq} R_{P,1} \overset{?}{\leq} R_{P,2}(0) \overset{?}{\leq} R_{L,2} \overset{?}{\leq} R$$

R represents the project return. $R_{H,2}$ and $R_{L,2}$ are the period 2 interest rates offered to plums (11) and lemons (12) under perfect information. To break even under imperfect information in period 2, banks offer either $R_{P,2}(0)$ or $R_{P,2}(R)$ conditional on period 1 default (8) or success (9). $R_{P,1}$ is the pooling rate banks offer without any information in period 1 (14). If a bank overcharges these break-even rates, its competitors can undercut profitably, while undercutting creates a loss on average.

To investigate the strictly increasing relationship between interest rates, we plug the interest rate formulas from sections 4.1.2 and 4.1.3 into the equation below and reduce the resulting fractions to lose $\bar{R}$. Finally, in combination with proposition 1 inverting the fractions shows that the proposed inequality relationship holds for all rates.

$$\begin{aligned}
& R_{H,2} \overset{?}{<} R_{P,2}(R) \overset{?}{<} R_{P,1} \overset{?}{<} R_{P,2}(0) \overset{?}{<} R_{L,2} \\
\Leftrightarrow & \frac{\bar{R}}{p_H} < \frac{\bar{R}}{\mu(H|R)p_H + \mu(L|R)p_L} < \frac{\bar{R}}{\theta p_H + (1-\theta)p_L} < \frac{\bar{R}}{\mu(H|0)p_H + \mu(L|0)p_L} < \frac{\bar{R}}{p_L} \\
\Leftrightarrow & \frac{1}{p_H} < \frac{1}{\mu(H|R)p_H + \mu(L|R)p_L} < \frac{1}{\theta p_H + (1-\theta)p_L} < \frac{1}{\mu(H|0)p_H + \mu(L|0)p_L} < \frac{1}{p_L} \\
\Leftrightarrow & p_H > \mu(H|R)p_H + \mu(L|R)p_L > \theta p_H + (1-\theta)p_L > \mu(H|0)p_H + \mu(L|0)p_L > p_L \\
\overset{\text{Prop. 1}}{\Rightarrow} & R_{H,2} < R_{P,2}(R) < R_{P,1} < R_{P,2}(0) < R_{L,2}
\end{aligned}$$

However, banks can never charge more than the project return R without risking a market collapse, and thus all rates are capped by R for sufficiently low effort levels. In consequence, "$<$" becomes "$\leq$". In addition, if effort levels are below the banks' break-even thresholds, there is no lending. $\bar{R} \leq R_{H,2}$ follows directly from equation 11 and the assumption that entrepreneurs cannot exert more than 100% effort (i.e. $p_H \in [0,1]$). In total this shows that proposition 2 holds and

$$\bar{R} \leq R_{H,2} \leq R_{P,2}(R) \leq R_{P,1} \leq R_{P,2}(0) \leq R_{L,2} \leq R.$$

□

Proposition 3: Effort levels of uninformed entrepreneurs under imperfect information

$$p^U_{H,t} \overset{?}{>} p^U_{L,t} \ \forall t \in \{1, 2\}$$

In period 1, $p^U_{H,1} > p^U_{L,1}$ holds, when the numerator of $p^U_{H,1}$ is greater than the numerator of $p^U_{L,1}$, while the denominator of $p^U_{H,1}$ is equal or lower than the denominator of $p^U_{L,1}$ or vice versa. To show that this is fulfilled for period 1 interest rates, we examine the relationship between numerators (I) and denominators (II) in the following. In combination, (I) and (II) confirm that plums exert higher period 1 effort than lemons on average.

$$p^U_{H,1} > p^U_{L,1} \Leftrightarrow \frac{R - R_{P,1} + \frac{\Delta R}{2a_H}\big(R - R_{P,2}(0)\big)}{2a_H - \frac{(\Delta R)^2}{2a_H}} \underset{<\text{(II)}}{\overset{>\text{(I)}}{-}} \frac{R - R_{P,1} + \frac{\Delta R}{2a_L}\big(R - R_{P,2}(0)\big)}{2a_L - \frac{(\Delta R)^2}{2a_L}} > 0$$

$$\text{(I)} \qquad R - R_{P,1} + \frac{\Delta R}{2a_H}\big(R - R_{P,2}(0)\big) > R - R_{P,1} + \frac{\Delta R}{2a_L}\big(R - R_{P,2}(0)\big)$$

$$\Leftrightarrow \frac{1}{2a_H} > \frac{1}{2a_L} \Leftrightarrow a_H \overset{\text{Ass.}}{<} a_L.$$

$$\text{(II)} \qquad 2a_H - \frac{(\Delta R)^2}{2a_H} < 2a_L - \frac{(\Delta R)^2}{2a_L}$$

$$\Leftrightarrow 2a_L - \frac{(\Delta R)^2}{2a_L} - 2a_H + \frac{(\Delta R)^2}{2a_H} \overset{a_L > a_H}{>} 2a_L - \frac{(\Delta R)^2}{2a_L} - 2a_H + \frac{(\Delta R)^2}{2a_L} > 0$$

$$\Leftrightarrow 2a_L - \frac{(\Delta R)^2}{2a_L} - 2a_H - \frac{(\Delta R)^2}{2a_H} > 2a_L - 2a_H = a_L - a_H \overset{\text{Ass.}}{>} 0.$$

To show that the proposed " > "-relationship also holds for period 2, we apply the same logic as in period 1. While (II) is trivially satisfied by the assumption about the quality differences, (I) directly follows from $p^U_{H,1} > p^U_{L,1}$ shown above.

$$p^U_{H,2} > p^U_{L,2} \Leftrightarrow \frac{R + p_{H,1}\Delta R - R_{P,2}(0)}{2a_H} \underset{<\text{(II)}}{\overset{>\text{(I)}}{-}} \frac{R + p_{L,1}\Delta R - R_{P,2}(0)}{2a_L} > 0$$

In consequence, $p^U_{H,t} > p^U_{L,t}$ holds for both periods $t \in \{1,2\}$.

$$p^U_{i,1} \overset{?}{\geq} p^U_{i,2} \; \forall i \in \{H, L\}$$

Similar to the relationship between type-specific effort levels, we compare numerators (I) and denominators (II) of the interest rate formulas to show that the ">"-relationship holds over time.

$$\text{(I)} \qquad R - R_{P,1} + \frac{\Delta R}{2a_i} \underbrace{\big(R - R_{P,2}(0)\big)}_{maxR_{P,2}(0)=R \text{ (Prop. 2)}} - \big(R + p_{i,1}\Delta R - R_{P,2}(0)\big) \overset{?}{>} 0$$

$$\Leftrightarrow \cdots > R_{P,1} + R_{P,2}(0) - \underbrace{p_{i,1}}_{\geq 1} \Delta R > R_{P,1} + R_{P,2}(0) - \big(R_{P,2}(0) - R_{P,2}(R)\big) > 0$$

$$\Leftrightarrow \cdots > \cdots > R_{P,1} + R_{P,2}(0) > 0$$

$$\text{(II)} \qquad 2a_i - \underbrace{\left(2a_i - \frac{\overbrace{(\Delta R)^2}^{\Delta R \geq 0}}{2a_i}\right)}_{\leq 2a_i} \geq 0$$

As a result $p^U_{i,1} > p^U_{i,2}$ holds for all $i \in \{H, L\}$, and thus proposition 3 proofs to be true in total.

□

Proposition 4: Effort levels of uninformed entrepreneurs under perfect information

$$p^U_{H,t} \overset{?}{>} p^U_{L,t} \; \forall t \in \{1,2\}$$

To show that this proposition holds, we follow the same logic as in proposition 3. In period 1, the numerator $R - R_{P,1}$ - which results from the pooling of entrepreneurs in period 1 and the absence of stochastic price effects due to the distinct separation in period 2 - is constant over types, and thus we only need to show that the inequality holds true for the denominators. Again, this complies with our model's assumptions, and thus $p^U_{H,1} > p^U_{L,1}$ holds.

$$p^U_{H,1} > p^U_{L,1} \Leftrightarrow \frac{R - R_{P,1}}{2a_H} - \frac{R - R_{P,1}}{2a_L} > 0 \Leftrightarrow \frac{1}{2a_H} - \frac{1}{2a_L} > 0 \Leftrightarrow a_H \overset{\text{Ass.}}{<} a_L$$

In period 2, period 1 performance qualifies entrepreneurs for type-specific interest rates $R_{H,2} \leq R_{L,2}$ (proposition 2). This relationship between interest rates charged to plums and lemons trivially leads to (I), while (II) directly follows from the model assumption that $a_L > a_H > 0$. In consequence, $p^U_{H,2} > p^U_{L,2}$ also holds true for period 2.

$$p^U_{H,2} > p^U_{L,2} \Leftrightarrow \frac{R - R_{H,2}}{2a_H} \underset{<(\mathrm{II})}{\overset{\geq(\mathrm{I})}{-}} \frac{R - R_{L,2}}{2a_L} > 0$$

In total, this shows that $p^U_{H,t} > p^U_{L,t}$ is true for all $t \in \{1, 2\}$.

To proof the second part of proposition 4, we now examine the variation of effort levels over time.

$$p^U_{H,1} \overset{?}{<} p^U_{H,2} \Leftrightarrow \frac{R - R_{H,2}}{2a_H} - \frac{R - R_{P,1}}{2a_H} > 0 \Rightarrow R_{P,1} - R_{H,2} \overset{\text{Prop. 2}}{\geq} 0$$

$$p^U_{L,1} \overset{?}{>} p^U_{L,2} \Leftrightarrow \frac{R - R_{H,2}}{2a_H} - \frac{R - R_{P,1}}{2a_H} > 0 \Rightarrow R_{P,1} - R_{H,2} \overset{\text{Prop. 2}}{\geq} 0$$

In total, this shows that relationships formalized by proposition 4 hols over both types and time.

$\square$

Proposition 5: Lock-in effect under imperfect information

$$p^I_{H,2} \overset{?}{<} p^U_{H,2}, \qquad p^I_{L,2} \overset{?}{>} p^U_{L,2}$$

For plums, plugging in the formulas from equations (16) and (20) highlights that the difference between period 2 efforts of uninformed and informed plums lies in the realization of the interest rate advantage ΔR. Substituting $p^I_{H,1}$ for $p^U_{L,1}$ and simplifying the relationship between both effort levels leads to $p^U_{H,1} - p^U_{L,1} > 0$, of which the correctness directly follows from proposition 3.

$$p^U_{H,2} - p^I_{H,2} > 0 \Leftrightarrow \frac{R + p^U_{H,1}\Delta R - R_{P,2}(0)}{2a_H} - \frac{R + \overbrace{p^I_{H,1}}^{:=p^U_{L,1}} \Delta R - R_{P,2}(0)}{2a_H} > 0 \Leftrightarrow p^U_{H,1} - p^U_{L,1} \overset{\text{Prop. 3}}{>} 0$$

For lemons, the same logic applies but with an inverse direction (i.e. lemons raise their effort to mimic plums). In consequence, $p^I_{L,2} > p^U_{L,2}$ follows from proposition 3.

$$p^I_{L,2} - p^U_{L,2} > 0 \Leftrightarrow \frac{R + \overbrace{p^I_{L,1}}^{:=p^U_{H,1}} \Delta R - R_{P,2}(0)}{2a_L} - \frac{R + p^U_{L,1}\Delta R - R_{P,2}(0)}{2a_L} > 0 \Leftrightarrow p^U_{H,1} - p^U_{L,1} \overset{\text{Prop. 3}}{>} 0$$

In total, this shows that $p^I_{H,2} < p^U_{H,2}$ and $p^I_{L,2} > p^U_{L,2}$.

□

Proposition 6: Utility of mimicking entrepreneurs under imperfect information

$$U_i\big(p^U_{-i,1}, p^I_{i,2}\big) \overset{?}{<} U_i\big(p^U_{i,1}, p^U_{i,2}\big)\ \forall i \in \{H, L\}$$

To show that this inequality holds for plums, we analyze the changes in utility illustrated in Figures 7(a) and 7(b). In period 1, $\Delta U_{H,1} < 0$ is trivially satisfied as the deviation from equilibrium effort to $p^I_{H,1} = p^U_{L,1} < p^U_{H,1}$ (Prop. 3) creates an imbalance between marginal costs and returns. To show that plums never experience utility gains from mimicking, we now investigate how deceptive behavior in period 1 impacts utility in period 2:

$$\begin{aligned}\Delta U_{H,2} =& \big(MC_{H,2}(p^I_{H,2}) - MC_{H,2}(p^U_{H,2})\big)p^U_{H,2} + \frac{1}{2}\Big[\big(MC_{H,2}(p^I_{H,2}) - MC_{H,2}(p^U_{H,2})\big)(p^I_{H,2} - p^U_{H,2})\Big] \\ =& 2a_H(p^I_{H,2} - p^U_{H,2})p^U_{H,2} + \frac{1}{2}\Big[2a_H(p^I_{H,2} - p^U_{H,2})^2\Big] \\ =& \underbrace{a_H}_{>0 \text{ Ass.}} \underbrace{(p^I_{H,2} - p^U_{H,2})}_{<0 \text{ (Prop. 5)}} \underbrace{(p^I_{H,2} + p^U_{H,2})}_{>0} < 0\end{aligned}$$

Formally, this underlines that the lock-in effect creates an utility loss in period 2 ($\Delta U_{H,2} < 0$). In aggregate, these utility losses in period 1 and 2 indicate that mimicking does not provide any benefits for plums and leads to $U_H\big(p^U_{L,1}, p^I_{H,2}\big) < U_H\big(p^U_{H,1}, p^U_{H,2}\big)$.

For lemons, the situation is a bit more complex: While deviation from equilibrium leads to utility losses in period 1, increasing efforts $p^I_{L,2} > p^U_{L,2}$ in period 2 ((Prop. 5)) provides access to a lower expected interest rates and creates an utility gain.

$$\begin{aligned}\Delta U_{L,2} =& \big(MC_{L,2}(p^I_{L,2}) - MC_{L,2}(p^U_{L,2})\big)p^U_{L,2} + \frac{1}{2}\Big[\big(MC_{L,2}(p^I_{L,2}) - MC_{L,2}(p^U_{L,2})\big)(p^I_{L,2} - p^U_{L,2})\Big] \\ =& 2a_L(p^I_{L,2} - p^U_{L,2})p^U_{L,2} + \frac{1}{2}\Big[2a_L(p^I_{L,2} - p^U_{L,2})^2\Big] \\ =& \underbrace{a_L}_{>0 \text{ Ass.}} \underbrace{(p^I_{L,2} - p^U_{L,2})}_{>0 \text{ (Prop. 5)}} \underbrace{(p^I_{L,2} + p^U_{L,2})}_{>0} > 0\end{aligned}$$

However, to show that these utility gains cannot outweigh the utility loss in period 1, we need to investigate whether the net utility change $\Delta U_L = \Delta U^U_{L,1} + \Delta U^U_{L,2}$ remains negative in all cases. Note that in the following, we compute the ΔU_L from a cost perspective $\Delta U_L = \Delta U^U_{L,1} - \Delta U^U_{L,2}$ and therefore costs dominate, when $\Delta U_L > 0$.

$$\begin{aligned}
\Delta U_L =& \frac{1}{2}\Big[\big(MC^U_{L,1}(p^U_{H,1}) - MC^U_{L,1}(p^U_{L,1})\big)(p^U_{H,1} - p^U_{L,1})\Big] \\
&- \frac{1}{2}\Big[\big(MR^U_{L,1}(p^U_{H,1}) - MR^U_{L,1}(p^U_{L,1})\big)(p^U_{H,1} - p^U_{L,1})\Big] \\
=& \frac{1}{2}\Big[\big(2a_L((p^U_{H,1} - p^U_{L,1})) + \frac{\Delta R^2}{2a_L}(p^U_{H,1} - p^U_{L,1})\big)(p^U_{H,1} - p^U_{L,1})\Big] - \frac{1}{2}\frac{\Delta R^2}{a_L}(p^U_{H,1} - p^U_{L,1})^2 \\
=& \frac{1}{2}\underbrace{(p^U_{H,1} - p^U_{L,1})^2}_{>0 \text{ Prop. 3}}\underbrace{\Big[2a_L + \frac{\Delta R^2}{2a_L} - \frac{\Delta R^2}{a_L}\Big]}_{>0 \text{ (I)}} > 0
\end{aligned}$$

The inequality of part (I) follows from the following logic: To estimate a lower bound, we first let $a_L \to 0$. As $a_L > a_H > 0$, this also pushes $a_H \to 0$ and infinitely cheap effort consequently raises effort levels for both types infinitely close to 1. As a result of these extremely high effort levels and the minimal difference in quality, interest rates rise and converge to R, and thus $\Delta(R) \to 0$. If we take a look a the equation below, we can easily see that this movement towards 0 is twice as fast for ΔR than for a_L. In addition, the fraction-based functional form of interest rates (i.e. $\frac{R}{\alpha p_H + (1-\alpha)p_L}$, where α represents some distribution of entrepreneurs) leads to an even stronger decrease compared to the quadratic and linear formalization of the disutility and return created by efforts. In consequence, $2a_L - \Delta R$ always remains > 0[16], and thus (I) holds true as long as lending occurs.

$$2a_L + \frac{\Delta R^2}{2a_L} - \frac{\Delta R^2}{a_L} = 4a_L^2 - \Delta R^2 > 0 \Leftrightarrow 2a_L > \Delta R$$

Eventually, this shows that $U_L\big(p^I_{L,1}, p^I_{L,2}\big) = U_L\big(p^U_{H,1}, p^I_{L,2}\big) < U_L\big(p^U_{L,1}, p^U_{L,2}\big)$ is true. In aggregate, the perspective of plums and lemons indicate that proposition 6 holds whenever lending occurs (i.e. $p_{i,t} > 0 \; \forall i \in \{H, L\},\; t \in \{1, 2\}$). □

Proposition 7: Lock-in effect under perfect information

$$p^I_{H,2} \overset{?}{<} p^U_{H,2}, \qquad p^I_{L,2} \overset{?}{>} p^U_{L,2}$$

[16]">" holds furthermore true as we never reach 0.

Comparing the perfect information interest rates banks offer to uninformed (18) and informed (22) plums highlights the negative relationship between efforts and prices. In consequence, $p^I_{H,2} < p^U_{H,2}$ directly follows from proposition 2.

$$p^U_{H,2} - p^I_{H,2} > 0 \Leftrightarrow \frac{R - R_{H,2}}{2a_H} - \frac{R - R_{L,2}}{2a_H} > 0 \Leftrightarrow -R_{H,2} - (-R_{L,2}) > 0 \Leftrightarrow R_{L,2} - R_{H,2} \overset{\text{Prop. 2}}{>} 0$$

For lemons, the same logic applies with an inverse price effect and $p^I_{L,2} > p^U_{L,2}$ follows from proposition 2.

$$p^I_{L,2} - p^U_{H,2} > 0 \Leftrightarrow \frac{R - R_{H,2}}{2a_L} - \frac{R - R_{L,2}}{2a_L} > 0 \Leftrightarrow R_{L,2} - R_{H,2} \overset{\text{Prop. 2}}{>} 0$$

In total, this shows that plums and lemons are locked-in to their behavioral change from period 1 as $p^I_{H,2} < p^U_{H,2}$ and $p^I_{L,2} > p^U_{L,2}$. In addition, the strict inequality ">" holds as long as $R_{i,2} < R$, i.e. as long as effort levels are high enough (see section 4.1.2).

□

Proposition 8: Utility of mimicking plums under perfect information

$$U_H\big(p^I_{H,1}, p^I_{H,2}\big) \overset{?}{<} U_H\big(p^U_{H,1}, p^U_{H,2}\big)$$

Similar to imperfect information, plums experience an utility loss over both periods under perfect information. In period 1, $\Delta U_{H,1} < 0$ follows directly from $MR_{H,1} > MC_{H,1}$. In addition, lowering period 1 efforts to $p^I_{H,1} := p^U_{L,1}$ leads to a higher interest burden $R_{L,2} \geq R_{H,2}$. This burden lowers marginal returns $MR^U_{H,2} > MR^I_{H,2}$. In combination with the resulting decline of effort, utility drops and $\Delta U_{H,2} < 0$. To support that this reasoning holds whenever lending occurs and efforts are high enough, we refer to proposition 7. Panels 8(a) and 8(b) in figure 8 support this reasoning graphically.

$$\begin{aligned}
\Delta U_{H,1} &= \frac{1}{2}(p^U_{H,1} - \underbrace{p^I_{H,1}}_{:=p^U_{L,1}})\big(MC_{H,1}(p^U_{H,1}) - MC_{H,1}(\underbrace{p^I_{H,1}}_{:=p^U_{L,1}})\big) \\
&= \frac{1}{2}(p^U_{H,1} - p^I_{H,1})2a_H(p^U_{H,1} - p^I_{H,1}) = \underbrace{a_H}_{>0\text{ (Ass.)}} \underbrace{(p^U_{H,1} - p^I_{H,1})^2}_{>0\text{ (Prop. 4)}} > 0
\end{aligned}$$

$$\Delta U_{H,2} = p^I_{H,1}\big(MC_{H,2}(p^U_{H,2}) - MC_{H,2}(p^I_{H,2})\big) + \frac{1}{2}(p^U_{H,2} - p^I_{H,2})\big(MC_{H,2}(p^U_{H,2}) - MC_{H,2}(p^I_{H,2})\big)$$

$$= \underbrace{a_H}_{>0 \text{ (Ass.)}} \underbrace{(p^U_{H,2} - p^I_{H,2})}_{>0 \text{ (Prop. 7)}} \underbrace{(p^I_{H,2} + p^U_{H,2})}_{>0 \text{ (when lending occurs)}} > 0$$

In total, this shows that $U_H\big(p^U_{L,1}, p^I_{H,2}\big) = U_H\big(p^I_{H,1}, p^I_{H,2}\big) < U_H\big(p^U_{H,1}, p^U_{H,2}\big)$, and thus plums do not experience any gains from mimicking.

□

Proposition 9: Utility of mimicking lemons under perfect information

$$U_L\big(p^I_{L,1}, p^I_{L,2}\big) \overset{?}{>} U_L\big(p^U_{L,1}, p^U_{L,2}\big)$$

In contrast to plums, under perfect information lemons experience an utility loss in period 1 (as $MR_{L,1} < MC_{L,1}$) and an utility gain in period 2. However, unlike lemons in the imperfect information regime, period 2 gains of mimicking can outweigh its cost in period 1, thereby making deception in period 1 profitable. To investigate in which situations mimicking provides a profitable alternative, we examine when the net utility gain over both periods $\Delta U_L = \Delta U_{L,2} - \Delta U_{L,1} > 0$.

$$\Delta U_L = \Delta U_{L,2} + \Delta U_{L,1} > 0$$

$$\Leftrightarrow a_L(p^U_{L,2} - p^I_{L,2})(p^I_{L,2} + p^U_{L,2}) - a_L(\underbrace{p^I_{L,1}}_{:=p^U_{H,1}} - p^U_{L,1})^2 > 0$$

$$\Leftrightarrow \left(\frac{R - R_{H,2}}{2a_L} - \frac{R - R_{L,2}}{2a_L}\right)\left(\frac{R - R_{H,2}}{2a_L} + \frac{R - R_{L,2}}{2a_L}\right) - \left(\frac{R - R_{P,1}}{2a_H} - \frac{R - R_{P,1}}{2a_L}\right)^2 > 0$$

$$\Leftrightarrow \frac{1}{4a_L^2}\Big[(R_{L,2} - R_{H,2})(2R - R_{H,2} - R_{L,2})\Big] - \frac{(R - R_{P,1})^2}{4a_H^2} - \frac{2R_{P,1})^2}{2a_H 2a_H} + \frac{R_{P,1})^2}{4a_L^2} > 0$$

$$\Leftrightarrow \frac{1}{4a_L^2}\Big[(R_{L,2} - R_{H,2})(2R - R_{H,2} - R_{L,2})\Big] - (R - R_{P,1})^2 \frac{a_L^2 - 2a_H a_L + a_H^2}{4a_H^2 4a_L^2} > 0$$

$$\Leftrightarrow \frac{1}{4a_L^2}\Big[(R_{L,2} - R_{H,2})(2R - R_{H,2} - R_{L,2})\Big] - (R - R_{P,1})^2 \frac{(a_L - a_H)^2}{4a_H^2 4a_L^2} > 0$$

$$\Leftrightarrow \underbrace{\underbrace{\frac{(R_{L,2} - R_{H,2})(2R - R_{H,2} - R_{L,2})}{(R - R_{P,1})^2}}_{\text{Relative price effect}} - \underbrace{\frac{(\overbrace{a_L - a_H}^{\Delta a})^2}{a_H^2}}_{\text{Relative cost effect}}}_{\text{Net utility gain}} > 0$$

Eventually, the quality difference $\Delta a > 0$ and its connection to interest rates via[17] supports the inequality $\Delta U_L > 0$, and thus shows that $U_L\big(p^U_{H,1}, p^I_{L,2} = U_L\big(p^I_{L,1}, p^I_{L,2}\big)\big) > U_L\big(p^U_{L,1}, p^U_{L,2}\big)$.

□

Proposition 10: Welfare effect

$$\Delta W \overset{?}{>} 0$$

To evaluate the welfare effect ΔW of blockchain adoption, we compare the welfare generated by informed entrepreneurs (i.e. mimicking lemons) with the welfare generated by uninformed entrepreneurs. As the plums do not change their behavior, the $\Delta W_H = 0$. In addition, the costs of capital $\bar{R}$ are constant, and thus do not play a role in the comparison between informed and uninformed lemons. As a result, ΔW is reduced to the utility change of mimicking lemons, and thus $\Delta W > 0$ directly follows from proposition 9 and our assumption that there is at least on lemon/plum in the market.

$$\begin{aligned}
\Delta W =& W(p^U_{H,1}, p^U_{H,2}, p^I_{L,1}, p^I_{L,2}) - W(p^U_{H,1}, p^U_{H,2}, p^U_{L,1}, p^U_{L,2}) \\
=& (1-\theta)\big[p^I_{L,1}R - \bar{R} - V_L(p^I_{L,1}) + p^I_{L,2}R - \bar{R} - V_L(p^I_{L,2}) \\
& - p^U_{L,1}R + \bar{R} + V_L(p^U_{L,1}) - p^U_{L,2}R + \bar{R} + V_L(p^U_{L,2})\big] \\
=& (1-\theta)\Big[\underbrace{p^I_{L,1}R - V_L(p^I_{L,1}) - \big(p^U_{L,1}R - V_L(p^U_{L,1})\big)}_{\Delta U_{L,1}} + \underbrace{p^I_{L,2}R - V_L(p^I_{L,2}) - \big(p^U_{L,2}R - V_L(p^U_{L,2})\big)}_{\Delta U_{L,2}}\Big] \\
=& \underbrace{(1-\theta)}_{>0 \text{Ass.}} \underbrace{\Delta U_L}_{>0 \text{ Prop. 9}} > 0
\end{aligned}$$

□

Proposition 11: Market collapse

To break even in the face of perfect competition, banks use the success probabilities of past (uninformed generations) to compute adequate interest rates for plums and lemons. The break-even condition for period 2 is equal to:

$$\Pi^U_2 = \theta\big[p^U_{H,2}R_{H,2} - \bar{R}\big] + (1-\theta)\big[p^U_{L,2}R_{L,2} - \bar{R}\big] = 0$$

However, when lemons change their the resulting success probabilities the break-even con-

[17] For details on the underlying logic, we refer to proposition 6, where we apply the same but inverse rationale.

dition for period 2 does not hold anymore:

$$\begin{aligned}
&\Pi_2^I = \theta \underbrace{\left[p^U_{H,2} R_{H,2} - \bar{R}\right]}_{=0} + (1-\theta)\left[p^I_{L,2} R_{H,2} - \bar{R}\right] \stackrel{?}{=} 0 \\
\Leftrightarrow & p^I_{L,2} R_{H,2} - \bar{R} \stackrel{?}{=} 0 \Leftrightarrow p^I_{L,2} \frac{\bar{R}}{p^U_{H,2}} - \bar{R} \stackrel{?}{=} 0 \Leftrightarrow \frac{p^I_{L,2}\bar{R}}{p^U_{H,2}} - \frac{p^U_{H,2}\bar{R}}{p^U_{H,2}} \stackrel{?}{=} 0 \Leftrightarrow (p^I_{L,2} - p^U_{H,2})\bar{R} \stackrel{?}{=} 0 \\
\Leftrightarrow & \left(\frac{R - R_{H,2}}{2a_L} \underbrace{\overset{=}{\underset{>}{-}}}_{\text{Ass.}} \frac{R - R_{H,2}}{2a_H} \right) < 0
\end{aligned}$$

As a result, banks are not able to roll over their funding at the end of period 2 and go bankrupt.

□

B.2. *Calculus*

B.2.1. *Banking Perspective*

Period 2 break-even success probabilities (imperfect information):

$$\begin{aligned}
&\mu(H|0)p_H R + \mu(L|0)p_L R - \bar{R} \stackrel{!}{=} 0 \\
\Leftrightarrow & \frac{(1-p_H)\theta}{\theta(1-p_H) + (1-\theta)(1-p_L)} p_H R + \frac{(1-p_L)(1-\theta)}{\theta(1-p_H) + (1-\theta)(1-p_L)} p_L R - \bar{R} \stackrel{!}{=} 0 \\
\Leftrightarrow & (1-p_H)\theta p_H R + (1-p_L)(1-\theta)p_L R - \bar{R}\left[\theta(1-p_H) + (1-\theta)(1-p_L)\right] \stackrel{!}{=} 0 \\
\Leftrightarrow & (p_H - p_H^2)\theta R + (p_L - p_L^2)(1-\theta)R - \bar{R}\left[\theta(1-p_H) + (1-\theta)(1-p_L)\right] \stackrel{!}{=} 0
\end{aligned}$$

Solving for p_H or p_L respectively yields the corresponding upper and lower limits for for lending at the given rates p'_H, p''_H, p'_L, and p''_L for the period 1 defaulters. Applying the same approach to the break-even condition for successful entrepreneurs $\mu(H|R)p_H R + \mu(L|R)p_L R - \bar{R} \stackrel{!}{=} 0$ yields p'_H, p''_H, p'_L, and p''_L.

Period 1 Break-even success probabilities: In period 1, banks cannot distinguish between entrepreneurial types and offer a pooling rate to both of them. However, to provide lending at this rate, entrepreneurial effort levels need to allow banks to break even on the total pool's expected profits. For the lowest possible p_i's this means that $R_{P,1} = R$, while banks require all project returns to break even. Based on the profits under perfect competition $\theta p_H R + (1-\theta)p_L R - \bar{R} \stackrel{!}{=} 0$, this break-even threshold is given by $p_H + p_L \frac{(1-\theta)}{\theta} \geq \frac{\bar{R}}{\theta R}$ (I).

In consequence, when $p_L = 0$, the average success probability of plums $p_H(p_L = 0)$ has to be greater than or equal to $\frac{\bar{R}}{\theta R}$ (II). Similarly, $p_L(p_H = 0) \geq \frac{\bar{R}}{(1-\theta)R}$, when plums have zero success probability (III). Figure 10 illustrates the resulting lending areas for in greater detail (lending areas A and B). Note that when we assume $p_H > p_L$ - such as we do in section 4.1 for instance - the lending area is limited to probability combinations that comply with this restriction (lending area A only).

$$
\begin{aligned}
\text{(I)} \qquad & p_H = \frac{\bar{R} - (1-\theta)p_L R}{\theta R} \\
& \Leftrightarrow p_H = \frac{\bar{R}}{\theta R} - \frac{(1-\theta)p_L R}{\theta R} = \frac{\bar{R}}{\theta R} - \frac{(1-\theta)p_L}{\theta} \\
& \Rightarrow p_H + p_L \frac{(1-\theta)}{\theta} = \frac{\bar{R}}{\theta R}
\end{aligned}
$$

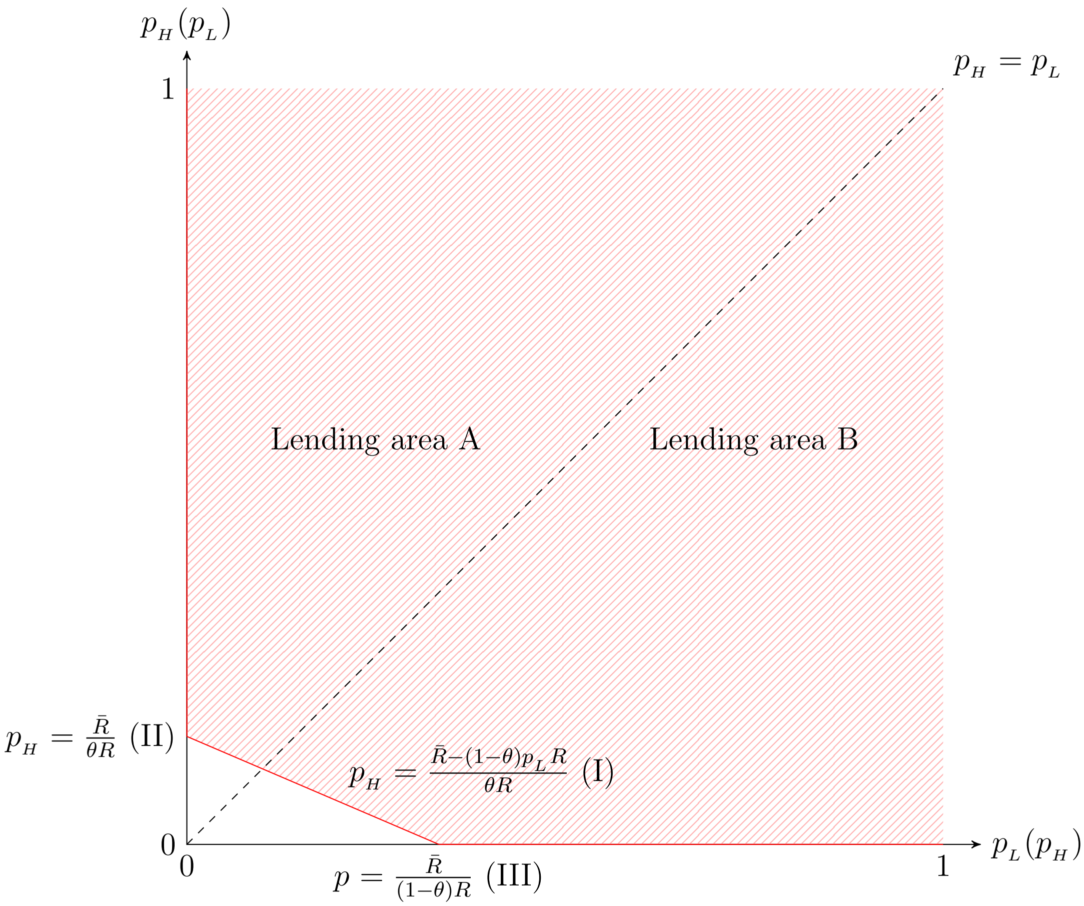


Fig. 10. Lending areas under full opacity and pooling.

B.2.2. Entrepreneurial Perspective

To find the optimal effort choices of entrepreneurs, we consider first and second order conditions and apply the following four-step approach: Step 1 identifies potential optimal effort levels in periods 1 and 2. Step 2 evaluates whether these choices are indeed maxima by showing that the determinant of the hessian matrix $|H_{U_i}| > 0$ and $\frac{\partial\partial U_i}{\partial p_{i,t}\partial p_{i,t}} < 0$. Step 3 checks whether the optimal effort levels lie within the defined range of $p_i \in (0, 1)$ Finally, step 4 compares entrepreneurial utility of the effort choices identified in step 1 with the utility at the boundary points $p_{i,t} = 0$ and $p_{i,t} = 1$. However, we keep this step short, as the convexity of utility trivially ensures that the argument holds for all combinations of boundary effort choices.

The difference between plums and lemons lies in the marginal cost of effort $(0 < a_i < a_L)$ and the resulting effort levels $(p_{H,t} > p_{L,t})$. In the uninformed scenarios, the limited access scope of the information system prevents entrepreneurs from learning about other entrepreneurs' behavior. As a result, they choose effort levels in periods 1 and 2 to maximize their individual utility independently of each other. In informed scenarios, entrepreneurs have knowledge about the average success probability of plums and lemons (from past generations), and thus can change their effort levels in period 1 in order to mimic the respective other type. Based on this change, they maximize their utility by choosing effort levels in period 2. In addition, the information available (imperfect/perfect) to the banks varies, and thus interest rates change accordingly. Eventually, this results in four analytic scenarios: Uninformed entrepreneurs who face imperfectly informed banks, uninformed entrepreneurs who face perfectly informed banks, informed entrepreneurs who face imperfectly informed banks, and informed entrepreneurs who face perfectly informed banks. To facilitate the understanding of the underlying rationale, we provide detailed calculations for the behavior of uninformed entrepreneurs under imperfect information. For the sake of brevity however, we limit the calculations for the remaining 3 scenarios to central results of each step.

Effort choices of uninformed entrepreneurs in the imperfect information regime: In the imperfect information regime, banks have to rely on project outcomes from period 1 (i.e. default (0) or success (R)) to approximate entrepreneurial types. As a result, both plums and lemons are offered a pooling rate dependent on default or success in period 1.

Note that entrepreneurs only differ in their marginal cost of effort $(0 < a_H < a_L)$. In consequence, we formalize rationales from a general perspective and denote type-specific variables with the subscript $i \in \{H, L\}$.

$$\begin{aligned}
U_i\big(p_{i,1}, p_{i,2}\big) =& \underbrace{p_{i,1}\big(R - R_{P,1}\big) - a_i p_{i,1}^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\big(R - E[R_{P,2}]\big) - a_i p_{i,2}^2}_{\text{Period 2 utility}} \\
=& p_{i,1}\big(R - R_{P,1}\big) - a_i p_{i,1}^2 + p_{i,2}\big(R - \big[p_{i,1} R_{P,2}(R) + (1 - p_{i,1}) R_{P,2}(0)\big]\big) - a_i p_{i,2}^2 \\
=& p_{i,1}\big(R - R_{P,1}\big) - a_i p_{i,1}^2 + p_{i,2}\big(R + p_{i,1} \underbrace{\big[R_{P,2}(0) - R_{P,2}(R)\big]}_{=\Delta R} - R_{P,2}(0)\big) - a_i p_{i,2}^2 \\
=& p_{i,1}\big(R - R_{P,1}\big) - a_i p_{i,1}^2 + p_{i,2}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big) - a_i p_{i,2}^2
\end{aligned}$$

Step 1: Identification of optimal effort choices

$$\begin{aligned}
\frac{\partial U_i}{\partial p_{i,2}} =& \underbrace{R + p_{i,1}\Delta R - R_{P,2}(0)}_{MR_{i,2}} - \underbrace{2a_i p_{i,2}}_{MC_{i,2}} \overset{!}{=} 0 \\
\Rightarrow p_{i,2}^U(p_{i,1}) =& \frac{R + p_{i,1}\Delta R - R_{P,2}(0)}{2a_i}
\end{aligned}$$

$$U_i\big(p_{i,1}, p_{i,2}^U(p_{i,1})\big) = p_{i,1}\big(R - R_{P,1}\big) - a_i p_{i,1}^2 + \underbrace{p_{i,2}^U(p_{i,1})\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)}_{\text{(I)}} - \underbrace{a_i\big(p_{i,2}^U(p_{i,1})\big)^2}_{\text{(II)}}$$

$$\begin{aligned}
\frac{\partial U_i}{\partial p_{i,1}} =& R - R_{P,1} - 2a_i p_{i,1} + \underbrace{\frac{\Delta R}{a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)}_{\text{(I)'}} - \underbrace{\frac{\Delta R}{2a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)}_{\text{(II)'}} \\
=& \underbrace{R - R_{P,1} + \frac{\Delta R}{a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)}_{MR_{i,1}} - \underbrace{2a_i p_{i,1} - \frac{\Delta R}{2a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)}_{MC_{i,1}} \\
=& R - R_{P,1} - 2a_i p_{i,1} + \frac{\Delta R}{2a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big) \\
=& R - R_{P,1} + \frac{\Delta R}{2a_i}\big(R - R_{P,2}(0)\big) + p_{i,1}\left(\frac{(\Delta R)^2}{2a_i} - 2a_i\right) \overset{!}{=} 0 \\
\Rightarrow p_{i,1}^U =& \frac{R - R_{P,1} + \frac{\Delta R}{2a_i}\big(R - R_{P,2}(0)\big)}{2a_i - \frac{(\Delta R)^2}{2a_i}}
\end{aligned}$$

$$\text{(I)} \qquad \frac{\partial(I)}{\partial p_{i,1}} = {p^U_{i,2}}'(p_{i,1}) \cdot \big(\dots\big) + p^U_{i,2}(p_{i,1}) \cdot \big(\dots\big)'$$
$$= \frac{\Delta R}{2a_i} \cdot \big(R + p_{i,1}\Delta R - R_{P,2}(0)\big) + \frac{R + p_{i,1}\Delta R - R_{P,2}(0)}{2a_i} \cdot \Delta R$$
$$= \frac{\Delta R}{a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)$$

$$\text{(II)} \qquad \frac{\partial(II)}{\partial p_{i,1}} = 2a_i p^U_{i,2}(p_{i,1}) \cdot {p^U_{i,2}}'(p_{i,1})$$
$$= 2a_i \frac{R + p_{i,1}\Delta R - R_{P,2}(0)}{2a_i} \cdot \frac{\Delta R}{2a_i}$$
$$= \frac{\Delta R}{2a_i}\big(R + p_{i,1}\Delta R - R_{P,2}(0)\big)$$

Step 2: Evaluation of optimal effort choices

$$\frac{\partial\partial U_i}{\partial p_{i,2}\partial p_{i,2}} = -2a_i, \quad \frac{\partial\partial U_i}{\partial p_{i,2}\partial p_{i,1}} = \Delta R, \quad \frac{\partial\partial U_i}{\partial p_{i,1}\partial p_{i,1}} = -2a_i, \quad \frac{\partial\partial U_i}{\partial p_{i,1}\partial p_{i,2}} = \Delta R$$

$$\Rightarrow H_{U_i} = \begin{pmatrix} -2a_i & \Delta R \\ \Delta R & -2a_i \end{pmatrix} \Rightarrow Det\big(H_{U_i}\big) = \begin{vmatrix} -2a_i & \Delta R \\ \Delta R & -2a_i \end{vmatrix} = \underbrace{(-2a_i)(-2a_i)}_{a_L > a_H > 0} - \underbrace{(\Delta R)^2}_{<1} > 0$$

$$\frac{\partial\partial U_i}{\partial p_{i,1}\partial p_{i,1}} = -2a_i < 0 \ \Rightarrow p^U_{i,1} \text{ is a maximum}, \quad \frac{\partial\partial U_i}{\partial p_{i,2}\partial p_{i,2}} = -2a_i < 0 \ \Rightarrow p^U_{i,2} \text{is a maximum}$$

Step 3: Admissibility of optimal effort choices

Proposition: $p^U_{i,2} \geq 0$

$$p^U_{i,2}(p_{i,1}) = \frac{R + p_{i,1}\Delta R - R_{P,2}(0)}{\underbrace{2a_i}_{>0}} \geq 0$$

$$\Leftrightarrow R + p_{i,1}\Delta R - R_{P,2}(0) \overset{min\ p_{i,1}=0}{\geq} \underbrace{R - R_{P,2}(0) \geq 0}_{\text{No lending for } R < R_{P,2}(0)} .$$

Even if plums do not exert effort in period 1, negative effort levels remain infeasible in period 2 as banks would not lend at these levels.

Proposition: $p^U_{i,2} \leq 1$

$$p^U_{i,2}(p_{i,1}) = \frac{R + p_{i,1}\Delta R - R_{P,2}(0)}{2a_i} \leq 1$$
$$\Leftrightarrow R + p_{i,1}\Delta R - R_{P,2}(0) \leq 2a_i$$
$$\Leftrightarrow R + p_{i,1}\Delta R - R_{P,2}(0) \overset{max\ p_{i,1}=1}{\leq} R + \underbrace{\Delta R}_{R_{P,2}(0)-R_{P,2}(R)} - R_{P,2}(0) \leq 2a_i$$
$$\Leftrightarrow R + p_{i,1}\Delta R - R_{P,2}(0) \leq \underbrace{R - R_{P,2}(R)}_{\text{Best case period 2 net return}} \leq 2a_i$$

Increasing the period 2 net return (in a best case scenario - i.e. when $p_{i,1} = 1$) can push plums' equilibrium effort levels in period 2 beyond the domain of $[0, 1]$. However, entrepreneurs cannot invest more than 100% effort. In consequence, we set $p^U_{i,2}$ to 1, if $R - R_{P,2}(R) > 2a_i$.

Proposition: $p^U_{i,1} \geq 0$

$$p^U_{i,1} = \frac{\overbrace{R - R_{P,1}}^{R_{P,1}=R \Rightarrow 0} + \overbrace{\frac{\Delta R}{2a_i}}^{\geq 0}(\overbrace{R - R_{P,2}(0)}^{max\ R_{P,2}(0)=R \Rightarrow \geq 0})}{\underbrace{2a_i - \frac{(\Delta R)^2}{2a_i}}_{\overset{?}{\geq} 0 \Rightarrow (\mathrm{I})}} \geq 0.$$

$$
\begin{aligned}
\text{(I)} \qquad & 2a_i - \frac{(\Delta R)^2}{2a_i} \geq 0 \mid \cdot 2a_i \\
& \Leftrightarrow (2a_i)^2 - (\Delta R)^2 \geq 0 \\
& \Leftrightarrow (2a_i)^2 \geq (\Delta R)^2 \mid \sqrt{} \\
& \Leftrightarrow 2a_i \geq \Delta R.
\end{aligned}
$$

The proposition $p^U_{i,1} \geq 0$ holds true, if the interest rate differential $R_{P,2}(0) - R_{P,2}(R) = \Delta R$ does not outweigh the marginal costs of effort: $2a_i \geq \Delta R$. We assume this to be true, as interest rates usually differ on the decimal level in practical contexts (a difference of 2 would be equal to 200 percentage points). Economically, this result indicates that in equilibrium plums exert positive effort as along as the marginal punishment for default is lower than the marginal cost of effort. The severity of punishment furthermore increases with the fraction of lemons in the market and their average success probability (see proposition 2).
Proposition: $p^U_{i,1} \leq 1$

$$
\begin{aligned}
& p^U_{i,1} = \frac{R - R_{P,1} + \frac{\Delta R}{2a_i}\big(R - R_{P,2}(0)\big)}{2a_i - \frac{(\Delta R)^2}{2a_i}} \leq 1 \\
& \Leftrightarrow R - R_{P,1} + \frac{\Delta R}{2a_i}\big(R - R_{P,2}(0)\big) \leq 2a_i - \frac{(\Delta R)^2}{2a_i} \\
& \Leftrightarrow R - R_{P,1} + \frac{\Delta R}{2a_i} R - \frac{\Delta R}{2a_i} R_{P,2}(0) \leq 2a_i - \frac{\Delta R}{2a_i}\big(R_{P,2}(0) - R_{P,2}(R)\big) \\
& \Leftrightarrow \underbrace{R - R_{P,1}}_{\text{Period 1 net return}} + \underbrace{\frac{\Delta R}{2a_i}\big(R - R_{P,2}(R)\big)}_{\text{Period 2 net benefit}} \leq 2a_i
\end{aligned}
$$

Similar to period 2, increasing period 1 net returns and period 2 net benefits can lead to equilibrium effort levels greater then 1 as U_i becomes strictly increasing. However, entrepreneurs still cannot invest more than 100% effort in each period. In consequence, we set $p^U_{i,1}$ to 1, if $R - R_{P,1} + \frac{\Delta R}{2a_i}\big(R - R_{P,2}(R)\big) > 2a_i$.

Step 4: Maximum utility and comparison to boundary points

In combination with $p_{i,t} \in [0, 1]$, the convexity of the total and partial utility (period 1, period 2) ensures that $U_i(p^U_{i,1}, p^U_{i,2})$ is indeed a maximum and no boundary points offer higher utility. In some special cases however – i.e. when $R - R_{P,2}(R) > 2a_i$ or $R - R_{P,1} + \frac{\Delta R}{2}\big(R - R_{P,2}(R)\big) > 2a_i$ – the optimal effort levels $p^U_{i,2}$ and $p^U_{i,1}$ can be equal to 1. In these special situations maximum utility is realized at the boundary of the specified domain of $p_{i,t}$.

Effort choices of uninformed entrepreneurs in the perfect information regime: In contrast to imperfect information, the information broker in the perfect information regime allows banks to acquire information about entrepreneurial types after period 1. As a result, they are able to offer risk-adjusted interest rates conditional on an entrepreneur's type at the beginning of period 2. In consequence, we apply the following logic to find the equilibrium effort choices of plums and lemons:

$$U_i(p_{i,1}, p_{i,2}) = \underbrace{p_{i,1}(R - R_{P,1}) - a_i p_{i,1}^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}(R - R_{i,2}) - a_i p_{i,2}^2}_{\text{Period 2 utility}}$$

Step 1: Identification of optimal effort choices

$$\frac{\partial U_L}{\partial p_{i,1}} = \underbrace{R - R_{P,1}}_{MR_{i,1}} - \underbrace{2a_i p_{i,1}}_{MC_{i,1}} \stackrel{!}{=} 0 \qquad \frac{\partial U_L}{\partial p_{i,2}} = \underbrace{R - R_{i,2}}_{MR_{i,2}} - \underbrace{2a_i p_{i,2}}_{MC_{i,2}} \stackrel{!}{=} 0$$

$$\Rightarrow p_{i,1}^U = \frac{R - R_{P,1}}{2a_i} \qquad \Rightarrow p_{2,1}^U = \frac{R - R_{i,2}}{2a_i}$$

Step 2: Evaluation of optimal effort choices

$$H_{U_L} = \begin{pmatrix} -2a_i & 0 \\ 0 & -2a_i \end{pmatrix} \Rightarrow Det(H_{U_L}) = \begin{vmatrix} -2a_i & 0 \\ 0 & -2a_i \end{vmatrix} = \underbrace{(-2a_i)(-2a_i)}_{a_i > 0} - 0^2 > 0.$$

$$\frac{\partial \partial U_L}{\partial p_{i,1} \partial p_{i,1}} = -2a_i < 0 \Rightarrow p_{i,1}^U \text{ is a maximum,} \qquad \frac{\partial \partial U_H}{\partial p_{i,2} \partial p_{i,2}} = -2a_i < 0 \Rightarrow p_{i,2}^U \text{is a maximum}$$

Step 3: Admissibility of optimal effort choices

$$p_{i,1}^U = \frac{\overbrace{R - R_{P,1}}^{max\ R_{P,1} = R}}{\underbrace{2a_i}_{a_i > 0}} \geq 0, \qquad p_{i,2}^U = \frac{\overbrace{R - R_{i,2}}^{max\ R_{i,2} = R}}{\underbrace{2a_i}_{a_i > 0}} \geq 0.$$

$$p_{i,1}^U = \frac{R - R_{P,1}}{2a_i} \leq 1. \qquad p_{i,2}^U = \frac{R - R_{i,2}}{2a_i} \leq 1.$$

Similar to the previous scenarios, high net returns can push $p^U_{i,t}$ beyond 1, and thus we set $p^U_{i,t} := 1$ in these cases.

Step 4: Comparison to boundary points

The inferiority of boundary points follows directly from the (strict) convexity of U_L.

Effort choices of informed entrepreneurs in the perfect information regime: We implement the deceptive behavior of entrepreneurs by setting period 1 effort levels to a fixed value $p^U_{-i,1}$ drawn from the blockchain-based information system. To find period 2 choices, we then use the resulting utility function and the conditional interest rates charged under pooling to find $p^I_{i,2}$.

$$\begin{aligned} U_i\big(p^U_{-i,1}, p_{i,2}\big) =& \underbrace{p^U_{-i,1}\big(R - R_{P,1}\big) - a_i (p^U_{-i,1})^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\big(R - E[R_{P,2}]\big) - a_i p^2_{i,2}}_{\text{Period 2 utility}} \\ =& p^U_{-i,1}\big(R - R_{P,1}\big) - a_i (p^U_{-i,1})^2 + p_{i,2}\big(R + p^U_{-i,1}\Delta R - R_{P,2}(0)\big) - a_i p^2_{i,2} \end{aligned}$$

Step 1: Identification of optimal effort choices

$$\begin{aligned} \frac{\partial U_i}{\partial p_{i,2}} =& \underbrace{R + p^*_{-i,1}\Delta R - R_{P,2}(0)}_{MR_{i,2}} - \underbrace{2a_i p_{i,2}}_{MC_{i,2}} \stackrel{!}{=} 0 \\ \Rightarrow p^I_{i,2}(p^U_{-i,1}) =& \frac{R + p^*_{-i,1}\Delta R - R_{P,2}(0)}{2a_i} \end{aligned}$$

Step 2: Evaluation of optimal effort choices

The second order condition is satisfied, because of the convexity of U_i directly follows from the convexity of V_i. More specifically, $\frac{\partial \partial U_i}{\partial p_{i,2}\partial p_{i,2}} = -2a_H < 0 \ \forall i \in \{H, L\}$. In addition, this holds true for both types, as marginal effort is strictly more expensive for lemons but always positive $(0 > a_H > a_H)$. As a result, $p^I_{i,2}$ proofs to be a maximum.

Step 3: Admissibility of optimal effort choices

The admissibility of $p^I_{i,2}$ follows the same principle as in the other cases before: $p^I_{i,2}$ is greater than 0 as both numerator and denominator are both ≥ 0. In consequence, all $p^I_{i,2}$ trivially qualify as admissible. With respect to the upper bound of $p_{i,2} \leq 1$ we set $p^I_{i,2}$ to 1, whenever high net returns or low marginal costs would push effort beyond 100%. More specifically, we set $p^I_{i,2}$ to 1, if $R - R_{P,2}(R) > 2a_i$ and $p^I_{H,1}$ to 1.

Step 4: Comparison to boundary points

Again, the convexity of total and partial utility - which follows directly from the strict convexity of V_i - ensures the validity of $p^I_{i,2}$.

Effort choices of informed entrepreneurs in the perfect information regime: Similar to imperfect information, entrepreneurs set period 1 efforts to effort levels from their counterparts to mimic them. The lending bank then acquires this from the information system at the beginning and offers a type-specific interest in the period 2 separating equilibrium. In consequence, utility for type i is equal to:

$$U_i\left(p^U_{-i,1}, p_{i,2}\right) = \underbrace{p^U_{-i,1}\left(R - R_{P,1}\right) - a_i(p^U_{-i,1})^2}_{\text{Period 1 utility}} + \underbrace{p_{i,2}\left(R - R_{-i,2}\right) - a_i p^2_{i,2}}_{\text{Period 2 utility}}$$

Step 1: Identification of optimal effort choices

$$\frac{\partial U_L}{\partial p_{i,2}} = \underbrace{R - R_{-i,2}}_{MR_{i,2}} - \underbrace{2a_i p_{i,2}}_{MC_{i,2}} \stackrel{!}{=} 0$$
$$\Rightarrow p^I_{i,2} = \frac{R - R_{-i,2}}{2a_i}$$

Step 2: Evaluation of optimal effort choices

Analogous to the imperfect information regime, the second order condition is trivially satisfied, because of the convexity of U_i. More specifically, $\frac{\partial\partial U_i}{\partial p_{i,2}\partial p_{i,2}} = -2a_i < 0 \; \forall i \in \{H, L\}$, as marginal effort is strictly more expensive for lemons but always positive $(0 > a_H > a_H)$. As a result, $p^I_{i,2}$ proofs to be a maxmimum for both types respectively.

Step 3: Admissibility of optimal effort choices

$$p^I_{i,2} = \frac{\overbrace{R - R_{i,2}}^{max\ R_{i,2}=R}}{\underbrace{2a_i}_{a_i>0}} \geq 0, \qquad p^I_{i,2} = \frac{R - R_{-i,2}}{2a_i} \leq 1.$$

Similar to the other cases, high net returns and/or low marginal costs can push $p^I_{i,2}$ beyond 1, and thus we set $p^I_{i,t} := 1$ in these cases.

Step 4: Comparison to boundary points

The inferiority of boundary points follows directly from the (strict) convexity of U_i.

Appendix C. Related Literature

C.1. Information Sharing Arrangements in Practice

Sharing information helps to mitigate problems associated with asymmetric information and improves market efficiency. In practice, information sharing takes place via centralized institutions that set and govern the rules of the information exchange. In credit markets - the analytic environment we arrange this study in - information sharing arrangements are either set up by superior institutions as public credit registries or form endogenously as private credit bureaus. This section illustrates the features of both and highlights differences.

	Public Credit Registries	**Private Credit Bureaus**
Purpose	• Support the state's role as a supervisor of financial institutions • Collect information on standing borrowers and make it available to the actual and potential lenders (i.e. the reporting financial institutions) and regulators • Usually no provision of value-added services • Focus on banking supervision	• Cater to the information requirements of commercial lenders • Provide value-added services, such as credit scores, collection services • Collect comprehensive data to asses and monitor the creditworthiness of individual clients • Exchange of information among banks and financial institutions
	• Theoretical substitutes: Public credit registers are set up to compensate for the lack of private information sharing arrangements, having been created mostly where no private credit bureaus existed • Practice: Private and public credit reporting systems of coexist and cater to different segments of the credit market	
Ownership & Operation	• Public entities created by national government authorities and managed by central banks, supervision agencies, or other regulatory authorities • Single entity per (national) market	• Set up, owned, and managed by commercial enterprises or non-profit organizations • Borrowers have the right to inspect data and request deletions or corrections • Potentially competing multinational operations

	Public Credit Registries	Private Credit Bureaus
Coverage	• Loans made by regulated financial institutions • All loans above the reporting threshold must be registered • Compulsory participation imposed by regulation based on rules dictated by law • Resulting from their national regulatory origin, public credit registries cover only intra-national loans and struggle with the international integration of capital markets	• Detailed information on small business loans, consumer credit, and trade credit provided by financial and non-financial lenders • Gather and process information on firms and individuals from multiple sources, including credit markets, lenders, and suppliers • Voluntary participation based on the principle of reciprocity and rules based on contractual agreements • In most jurisdictions data storage is limited to a certain amount of time (e.g. European Commission (2018))
Data	• Information about the type, terms, and structure of outstanding loans • Personal & identifying information	• Information about the type, terms, and structure of individual loans, repayment histories and performance of individual standing borrowers • Integration of hard, soft (Liberti and Petersen, 2017), black, and white information from additional sources such as public records, demographic databases or lawsuits
Summary	Universal coverage of loans above a specified threshold, which mainly consists of credit data and is disseminated in consolidated form as the total loan exposure of a borrower	Incomplete but detailed coverage of individual loans, which is merged with credit data and other data to enable a comprehensive assessment of individual borrowers
References	Pagano and Jappelli (1993); Padilla and Pagano (2000); Jappelli and Pagano (2002); Djankov et al. (2007); World Bank (2011, 2013)	

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