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Payments and privacy in the digital economy[☆]

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ABSTRACT

We propose a model of lending, payments choice, and privacy in the digital economy. While digital payments enable merchants to sell goods online, they reveal information to their lender. Cash guarantees anonymity, but limits distribution to less efficient offline venues. In equilibrium, merchants trade off the efficiency gains from online distribution (with digital payments) and the informational rents from staying anonymous (with cash). While new technologies can reduce the privacy concerns associated with digital payments, they also redistribute surplus from the lender to merchants. Hence, privacy enhancements do not always improve welfare.

1. Introduction

The rise of the digital economy has profound implications for the economics of payments. As more goods and services are sold online, physical currency ("cash") is becoming impractical as means of payment for a growing share of economic activity. At the same time, the speed and convenience of digital payments has increased tremendously due to the proliferation of mobile wallets and the launch of instant payment systems. Accordingly, the use of cash is declining fast.[1]

However, these developments are not without concern. Digital payments generate troves of data that reveal information about those making and receiving payments. It is well-known that the economic consequences of reduced privacy are ambiguous (Acquisti et al., 2016). This double-edged nature of data disclosure is also pervasive in credit markets. On the one hand, better information protects lenders from adverse selection and thus increases the availability of credit (Stiglitz and Weiss, 1981). On the other hand, more data also enables price discrimination and rent extraction (Boissay et al., 2021). Accordingly, a proliferation of data from digital payments may increase or decrease social welfare.

Privacy is a design feature of payments system that can be tailored to meet social needs and preferences. While the current system based on commercial bank money generates relatively large amounts of data, technological advances and regulatory initiatives can give rise to different environments. For example, advances in cryptography such as zero knowledge proofs (Goldwasser et al., 1989) and blockchain technology can enable decentralized transaction settlement with high levels of privacy. Similarly, public digital money in the form of central bank digital currency (CBDC) could have a comparative advantage at providing privacy because it is not bound by profit-maximizing

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[1] See, for example, Table III.1 in Bank for International Settlements (2021).

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incentives or political motives.[2]

Given this background, what is the optimal design for digital payment instruments? This paper speaks to this question by developing a stylized model of lending to analyze the interconnections of payments and privacy in the context of the digital economy. In our model, heterogeneous sellers require outside finance for two rounds of production. They privately learn their type (high (H) or low (L)) in the initial round of production, and only H-sellers generate a continuation payoff that merits re-financing. The lender wants to learn sellers' type to (i) extract the maximum surplus from first-round production, and (ii) to avoid adverse selection on the second loan. While the lender is a monopolist, her ability to set loan terms is disciplined by sellers' outside option.

Sellers can distribute their goods offline (through a brick-and-mortar store) or online (over the internet). Online distribution is efficient in the sense that it generates high sales. However, online transactions must be settled with digital payment means, which leave a trace ("signal") observable to the lender. By contrast, offline sales create a relatively low surplus, but they can be settled in cash without any digital footprint. This forces the lender to elicit information through contractual terms ("screening"), enabling sellers to earn some informational rents. These rents constitute sellers' endogenous benefit of privacy.

The dichotomy between sales efficiency and privacy creates the following trade-off for sellers. Online distribution creates a large surplus, but the lack of privacy that arises from the need to use digital payments leaves sellers with a relatively small share of this surplus. By contrast, offline distribution generates less surplus, but the privacy brought about by cash guarantees that sellers can appropriate a larger share of it. If the benefits of more efficient sales outweigh the loss of informational rents associated with privacy, sellers distribute online.

While online distribution is efficient, there are three inefficiencies when sellers choose to stay offline. First, offline distribution generates a low level of sales. Second, the lender may find it too costly to elicit all information through contractual terms. In this case, only some, but not all, H-sellers will be re-financed, and additional future output is lost. And third, the lender may refuse to extend the initial loan because the informational rents appropriated by sellers are too high and prevent the lender from recovering her cost of funds.

Our benchmark case of perfectly informative payment flows is inspired by traditional payments systems centered around bank deposits ("$\mathcal{D}$-money") that constitute a significant source of information for banks.[3] We then extend the model to speak to recent developments that challenge this status quo, for example through changes in the competitive landscape, the rise of new technologies, or regulation.

First, we study the equilibrium when the design of digital money includes privacy-preserving features (called "$\mathcal{P}$-money"). This is inspired by the gravitation of payments data outside of the banking sector (via non-bank PSPs), the development of privacy-preserving technologies, and the debate on CBDCs. In the context of our model, this means that the lender no longer gets a signal from payments.

Then $\mathcal{P}$-money enables sellers to capture the best of both worlds. They can reap some of the efficiency gains of online distribution, and at the same time earn informational rents from remaining anonymous. This raises welfare by (i) increasing sellers' incentives to distribute online and (ii) inducing the lender to always elicit full information, so that her refinancing decisions are efficient. However, the resulting re-distribution of surplus towards sellers implies that the lender finds it more difficult to cover her cost of funds. As a result, she may refuse to grant the initial loan in case sellers' outside option is sufficiently large, which reduces welfare. Notably, $\mathcal{P}$-money does not fully crowd out cash because the latter can generate higher informational rents under some conditions. Accordingly, the equilibrium with $\mathcal{P}$-money can still feature offline distribution.

Second, we analyze the case where users have control over the data generated by payments. Such a design of digital payments reflects a broader notion of privacy (Hughes, 1993; Acquisti et al., 2016), and is consistent with initiatives aimed at increasing end-user control over the data they help generate, such as "open banking" regulations. In our model, this new type of money ("$\mathcal{C}$-money") enables sellers to choose whether the lender receives a signal or not, and at what time. We show that, in equilibrium, sellers decide to reveal a perfect signal after the repayment of the first loan. This timing choice separates the bright side (generating continuation finance) from the dark side (rent extraction) of informative payment flows, and guarantees that sellers always opt for online distribution. However, by empowering merchants, $\mathcal{C}$-money exacerbates the pressure on the lender's profit margin, which increases the range of parameters for which she is not willing to grant the initial loan.

Since no form of digital money is unequivocally optimal, we close our analysis by studying the problem of a social planner that faces ex-ante uncertainty about sellers' outside option and chooses the available digital payment instrument to maximize utilitarian welfare. We find that privacy (i.e. $\mathcal{P}$-money) is optimal for most parameter configurations because it strikes a balance between (i) providing incentives for sellers to distribute online and (ii) ensuring that the lender is able to extract sufficient surplus to cover her cost of funds. The additional feature of end-user control ($\mathcal{C}$-money) is only beneficial when the social gains from online distribution are small and sellers have poor outside options. Otherwise, the concomitant re-distribution of rents from the lender to sellers is "too large" in the sense that it can induce a breakdown of the lending market. Similarly, traditional payment methods such as deposits ($\mathcal{D}$-money) are optimal whenever the social benefits of online distribution are large and sellers are able to appropriate a sufficient share of these gains.

Literature. Our paper is related to the literature on privacy in payments. In Kahn et al. (2005), cash payments preserve the anonymity of the purchaser, which provides protection against moral hazard (modeled as the risk of theft). This is different from the benefit of anonymity in our model, which is a reduced rent extraction in the lending market. Moreover, we also study new trade-offs associated with the choice of trading venues and their interactions with the privacy design of digital payments.

Garratt and Van Oordt (2021) is also a closely related paper. They study a setting in which merchants use information gleaned from current customer payments to price discriminate future customers.[4] Customers can take costly actions to preserve their privacy in payments but fail to appreciate the full social value of doing so. Overall investment in privacy protection thus falls short of the social optimum, similar to a public goods problem. Instead of analyzing this externality, we focus on the private benefits and costs of privacy in payments, which we endogenize. Specifically, the benefits arise from informational rents in a contracting problem, while the costs arise from lower sales due to inefficient offline distribution.

Our paper builds on work studying the interaction of payments and lending. A large empirical literature (see, e.g., Black, 1975; Mester et al., 2007; Norden and Weber, 2010; Puri et al., 2017; Ouyang, 2023; Ghosh et al., 2024) suggests that payment flows are informative about borrower quality. Parlour et al. (2022) study a screening model where

[2] Major central banks have pledged to include privacy-preserving features, likely also in response to citizens' concerns. For example, privacy has been named as number one concern in the Eurosystem's public consultation on a digital euro (European Central Bank, 2021).

[3] For example, the consultancy firm PwC argues that "payments generate roughly 90% of banks' useful customer data". See "Navigating the payments matrix–Payments 2025 & beyond", available at https://www.pwc.com/gx/en/industries/financial-services/publications/financial-services-in-2025/payments-in-2025.html.

[4] Kang (2024) uses a similar idea, although in his set up data helps to improve the matching of goods and customers' preferences.

banks face competition for payment flows by FinTechs. While such competition may improve financial inclusion, it affects lending and payment pricing by threatening the information flow to banks. Relative to their contribution, we explicitly model the link between the signal and payments data. As a result, we show that the bank may prefer a contract that does not lead to full separation, which gives rise to other types of inefficiencies. Moreover, we study a broader definition of end-user control over payments data that includes the ability to time the possible data release.

He et al. (2023) study competition between banks and Fintech in lending markets with consumer data sharing. They find that open banking can hurt borrowers when lenders have different abilities to analyze the data shared by the borrower. In this case, there is a winner's curse that can discourage participation of the lender with the worse data-analysis technology. Rather, we find that a digital payment technology with data-sharing features can be beneficial because it enables an "informational level-playing field" among lenders, as empirically documented by Babina et al. (2024). Finally, Agur et al. (2023) study the privacy policy and data sales decisions of a "BigTech" digital payments provider. Unlike in our model, privacy is a fully exogenous cost to end-users in their setting.

Other theoretical work considers how the payment choice may signal the borrower's quality and affects lending market outcomes. Ghosh et al. (2024) offer a model of a competitive lending market in which borrowers signal their propensity to divert funds (and thus default) via their choice of payment technology. The cost of default depends on the information received from payments. In Cheng and Izumi (2024), the choice of payment method affects the enforcement capability of the lender. By contrast, our focus is on how a lender with some market power can screen borrowers and how this is influenced by the choice of payment instruments. Rent distribution in the payment system is also a key feature in Auer et al. (2024).

Finally, our paper is related to the fast-growing literature on CBDC (Ahnert et al., 2022). The interaction of payments information and credit supply in our model relates to work analyzing the effects of CBDC on bank disintermediation (Andolfatto, 2021; Keister and Sanches, 2022; Chiu et al., 2023). Brunnermeier and Payne (2022) develop a model of platform design under competition with a public marketplace and a potential entrant, and study how different forms of interoperability are affected by regulation (including CBDC). In Garratt and Lee (2021), privacy features of CBDC are a way to maintain an efficient monopoly in data collection. And in Keister and Monnet (2022), real-time information from the payment system improve the efficacy of bank resolution in crisis times.

Structure. The paper proceeds as follows. We introduce the basic model with cash and deposits in Section 2, and solve for the equilibrium with digital payment in Section 3. We then introduce alternative payment arrangements in Section 4, and study the social planner's optimal choice in Section 5. Section 6 concludes. All proofs are found in Appendix A, and additional results are described in the Online Appendix.

2. The basic model

There are four dates $t = 0, 1, 2, 3$ with no discounting, a single good, and two sets of risk-neutral agents: a lender (she) and a continuum of sellers (he/they) of unit mass.

Sellers. Sellers are of two types. A fraction $q \in (0,1)$ is of high type (H-sellers) and the remaining $1-q$ are of low type (L-sellers). L-sellers produce a good of low quality at $t = 1$ and nothing at $t = 3$. By contrast, H-sellers produce a good of high quality at $t = 1$, and output worth $\theta > 1$ at $t = 3$. Production at t requires an investment of one unit at $t-1$ that must be raised from the lender. Production is indivisible, and sellers privately learn their type at the beginning of $t = 1$.

Lender. The monopolistic lender is endowed with one unit of the good at $t = 0$ and $t = 2$. She always derives utility 1 from consuming one unit of the good, which is also her opportunity cost.

Loans. The lender makes take-it-or-leave it offers to sellers. The lender can neither commit to long-term contracts, nor to not renegotiating the loan terms. Hence, it is as if she could set the interest rates on her loan at $t = 1$ and $t = 3$, respectively. While the monopolistic lender has all the bargaining power, sellers can always abscond with a fraction $\lambda \in (0,1)$ of their sales or loaned good.[5]

Goods distribution. Sellers can distribute their goods via two different venues υ. They can either sell offline ($\upsilon = F$) via a brick-and-mortar store, or online ($\upsilon = O$) over the internet. Since their production is indivisible, they can only choose one of the two venues and they must do so at $t = 0$, i.e. before learning their type.[6]

We assume that online distribution yields a relatively high level of sales. In particular, it guarantees that H-sellers generates sales of p_H. By contrast, offline distribution is less efficient. Specifically, high-quality goods generate sales of p_H only with probability α, and are sold for $p_L < p_H$ with probability $1-\alpha$. Thus, α measures the relative efficiency of offline sales. We refer to H-sellers with high sales p_H as HH-sellers, and H-sellers with low sales p_L as HL-sellers. For simplicity, we assume that low-quality goods generate sales of p_L independently of the distribution venue. For notational ease, we denote expected sales on venue υ by $\overline{p}_\upsilon$, so that $\overline{p}_O = qp_H + (1-q)p_L$ and $\overline{p}_F = \overline{p}_O - (1-\alpha)q\Delta_p$, with $\Delta_p \equiv p_H - p_L$. In Online Appendix OA.2, we show how to endogenize this price structure using search frictions and Nash bargaining.

To make matters interesting, we assume that the payoff on the continuation project θ exceeds p_L, but at the same time is smaller than p_H.

Assumption 1. $p_H \geq \theta > p_L \geq 1$.

This assumption ensures that the lender can extract the full continuation surplus from HH-sellers but not from HL-sellers. Accordingly, she faces a non-trivial choice among different types of contract menus when sellers distribute their goods offline.[7]

Payments. Offline sales can be settled with physical currency ("cash"). This is too cumbersome for online sales, which therefore must be settled via a digital means of payment. However, unlike cash, such transactions create a digital footprint. In line with existing literature, we assume that digital payment flows are informative about borrowers' income. More precisely, when the digital payment for an online sale is processed, it generates a signal $\sigma(p)$ to the lender with $p \in \{p_H, p_L\}$ such that

$$\sigma(p) = \begin{cases} p & \text{with prob. } x \\ p' & \text{with prob. } 1-x, \quad p' \neq p, \end{cases}$$

where $x \geq 1/2$ denotes the precision of the signal. The lender observes a signal about the revenue and tries to infer both sellers' type and

[5] Alternatively, sellers' ability to extract a share of the surplus could arise from a moral hazard problem in the spirit of Holmstrom and Tirole (1997), whereby the lender needs to provide incentives for sellers to exert effort. We lay out the details for such an alternative model setup in Online Appendix OA.4.

[6] We think of distribution decisions as long-term, which sellers have to make before knowing the (entire) demand for their goods. Hence, they cannot condition the trading venue on their own quality. In Online Appendix OA.3, we alternatively assume that sellers learn their type before choosing the trading venue. We show the existence of a mimicking equilibrium in which the venue choice is uninformative, so that our baseline results go through.

[7] Alternatively, such a trade-off for the lender arises endogenously when prices are the result of Nash bargaining between sellers and prospective buyers. In this case, a feedback effect from continuation investment to sales prices creates variation in the informational rents that sellers can appropriate (see Online Appendix OA.2 for details).

their true revenue (more on this below). By contrast, the exchange of physical currency does not leave any trace. Accordingly, we assume that offline transactions settled in cash do not generate any signal.[8]

Timing and equilibrium definition. The timing is as follows. At $t = 0$, sellers try to borrow one unit from the lender and, in case of success, choose their distribution venue $v \in \{O, F\}$. At $t = 1$, sellers learn their type $\tau \in \{H, L\}$ and generate sales p. The pair $\pi = (\tau, p) \in \{H, L\} \times \{p_L, p_H\}$ is the seller's profile. The lender learns the signal $\sigma \in \{p_H, p_L, \emptyset\}$, where $\sigma = \emptyset$ whenever the seller trades offline or absconds. Given σ, the lender offers a contract menu $\{r_\sigma(\pi), k_\sigma(\pi)\}_{\sigma,\pi}$, where $r_\sigma(\pi)$ is the repayment of the initial loan and $k_\sigma(\pi) \in \{0, 1\}$ is an indicator whether a continuation loan is granted at $t = 2$, when a seller reports profile π. The lender also chooses the repayment R on the continuation loan at $t = 3$. H-sellers who have received a continuation loan produce θ and repay R, or abscond with the production to obtain a payoff $\lambda\theta$. L-sellers who have received a continuation loan abscond with it to obtain a payoff λ. Our equilibrium definition is as follows.

Definition 1. An equilibrium consists of an initial lending decision, a menu of contracts $\{r_\sigma(\pi), k_\sigma(\pi)\}_{\sigma,\pi}$, a repayment for the second loan R, a venue choice $v \in \{O, F\}$, and a reporting strategy $\hat{\pi} \in \{H, L\} \times \{p_L, p_H\}$ such that:

1. the lender decides upon the initial loan and chooses the contract menu $\{r_\sigma(\pi), k_\sigma(\pi)\}_{\sigma,\pi}$ as well as repayment on the second loan R to maximize expected profits, taking sellers venue choice and reporting strategy as given;
2. upon being granted the initial loan, sellers choose the venue v and reporting strategy $\hat{\pi}$ to maximize expected profits, taking $\{r_\sigma(\pi), k_\sigma(\pi)\}_{\sigma,\pi}$ and R as given.

As is standard, sellers report a profile that maps into a contract of repayment and a refinancing choice. It is as if sellers were choosing that contract and this is how we will think about the sellers report going forward.

Welfare. Four potential inefficiencies can arise in equilibrium. First, offline distribution is inefficient because it generates lower expected sales, as a fraction $1-\alpha$ of H-sellers only generates revenue p_L. Second, the lender may not extend the initial loan if the share of the surplus that she can extract is too low (i.e. λ is too high). Third, the lender may not re-finance all H-sellers at $t = 2$ if she is not fully informed about their type. Fourth, sellers may decide to abscond, which destroys resources because the fraction $1-\lambda$ of output is lost. Therefore, welfare is maximized whenever (i) the lender extends an initial loan to all sellers; (ii) all sellers distribute their goods online; (iii) the lender grants a second loan to all H-sellers but not to L-sellers; (iv) all sellers repay their loans. This efficiency benchmark is useful as we turn to the economy with asymmetric information.

Key parameters and mapping them to the real world. In what follows, we will solve for the equilibrium with different types of money that differ in terms of (i) signal precision x and (ii) the extent to which sellers can control the timing of the signal release. The two crucial parameters are λ and α. While λ formally represents the threat of absconding, we think of it as capturing real-world features such as the degree of competition in lending markets, or the level of legal contract enforcement. Similarly, α (the relative efficiency of offline distribution) could in reality correspond to factors such as sector-/country-specific exposure to technological innovation, or differences in market structure. We will further discuss these interpretations in Section 5.

3. Benchmark: Transparent digital payments

In this section, we solve for the equilibrium when digital payments provide a signal with high precision to the lender. We believe this benchmark is useful because of the structure of traditional payment systems. These are centered around banks and their ability to create deposits, or "commercial bank money". As providers of both means of payment and payment rails, banks derive a substantial amount of information from processing customer payment flows. This does not only include the amount and timing of payments, but also information on the parties involved and the purpose of the transaction. It is well-known that these data can then be used to assess and monitor borrower credit quality.

We therefore associate digital payment means with a high level of signal precision x to bank deposits or related payment instruments that leave a trace observable to the lender. We henceforth refer to them as $\mathcal{D}$-money (short for deposits). For simplicity, we assume that the signal is perfect, $x = 1$.[9] Since the lender observes digital payments activity in real time under such an arrangement, she is able to detect sellers' attempts of absconding by "catching them in the act". Hence we assume that absconding requires the diversion of cash flows through offshore accounts or the use of opaque accounting procedures, which renders the signal completely uninformative.[10]

To solve for the equilibrium, we proceed backwards. We start with the lender's decision to extend a continuation loan. We then solve for the optimal contract menu for the initial loan repayment, and then determine the seller's choice of trading venue. Finally, we study the lender's initial lending choice.

Lender refinancing choice. Since not all sellers produce output at $t = 3$, the lender's decision at $t = 2$ depends on whether she is informed about sellers' type. When she is informed, L-sellers do not receive a continuation loan because they will produce nothing and abscond with the loan. By contrast, H-sellers do generate output θ, so that the monopolistic lender will set a repayment of

$$R^* = (1-\lambda)\theta \tag{1}$$

and leave H-sellers with nothing in excess of their outside option $\lambda\theta$.

To make the analysis interesting, we require the repayment to cover at least the lender's unit cost of investment, since she would never grant a continuation loan otherwise. This is the case whenever $\lambda < \overline{\lambda} \equiv \frac{\theta-1}{\theta}$. Conversely, when the lender does not know the seller's type, she faces adverse selection and will only earn the repayment R^* with probability q. To simplify the analysis, we assume that this renders uninformed lending unprofitable. We ensure this by imposing $\lambda > \underline{\lambda} \equiv \max\{\frac{q\theta-1}{q\theta}, 0\}$.[11] We summarize these bounds as follows.

Assumption 2. $\lambda \in (\underline{\lambda}, \overline{\lambda})$.

For expositional clarity, we additionally impose bounds on the degree of adverse selection, q. The upper bound on q helps to reduce the number of contract menus that the lender will offer in equilibrium.[12] The lower bound ensures that the lender always breaks even when $\mathcal{D}$-money is used so that the equilibrium is efficient. This assumption is without loss of generality in the sense that it does not affect the welfare

8 Nothing would change if we also allowed offline sales to be settled digitally. Since digital payments do not entail a benefit for offline sales, merchants would choose not to accept digital payments but only cash.

9 The intuition developed here and in the next section carries over to the general case in which x can take any value in the interval $[\frac{1}{2}, 1]$, which we study in Online Appendix OA.1.

10 Importantly, the use of such procedures is not a separate choice from absconding, but rather a necessity.

11 Uninformed lending is unprofitable whenever $(1-\lambda)q\theta < 1$. For $q\theta < 1$, this is always true, so that no lower bound on λ is required. Otherwise, it holds whenever $\lambda > \frac{q\theta-1}{q\theta}$.

12 Specifically, it rules out a partial participation contract—see the Proof of Lemma 2 for details.

ranking of the various payment instruments considered. As we will see below, the lender earns the highest expected profits under $\mathcal{D}$-money. Taken together, we assume the following.

Assumption 3. $q \in (\underline{q}, \overline{q})$, where $\overline{q} \equiv \frac{p_L}{p_H}$ and $\underline{q} \equiv \frac{\theta - p_L}{\theta(\theta-1)+\Delta_p}$

Loan repayment at $t = 1$. Here we study the lender's choice of repayment the initial loan. We separately study the cases of online and offline distribution, since the lender's information set depends on the selected distribution venue.

When sellers distribute *online* and accept $\mathcal{D}$-money, the payment system perfectly reveals their type to the lender because sales and types are perfectly correlated with online distribution. Therefore, the repayments do not have to satisfy any incentive constraints and are fully pinned down by sellers' participation constraints. Hence, the lender refinances all H-sellers at $t = 2$.

Lemma 1. *Suppose that sellers choose online distribution with* $\mathcal{D}$*-money. Then, the lender sets repayments* $r_L^{\mathcal{D}} = (1-\lambda)p_L$ *and* $r_H^{\mathcal{D}} = (1-\lambda)p_H + \lambda\theta$.

In essence, the information from payment flows enables the lender to condition the contract terms on sellers' type. She can therefore extract the maximum possible surplus, which leaves sellers with nothing but their reservation value.

Under *offline* distribution with cash payments, the lender receives no signal. Accordingly, she must elicit information by offering an appropriate menu of contracts ("screening"). Ideally, the lender wants to learn sellers' full profile. Knowledge of the type allows her to choose refinancing appropriately, while knowledge of the level of sales enables her to set the repayment as high as possible. However, the fact that H-sellers sometimes realize low sales complicates the lender's inference problem and prevents her from acquiring all this information.

In choosing the optimal contract, the lender faces the following trade-off. She can either offer a *separating contract* with repayments (r_H^S, r_L^S) that identifies all H-sellers, or alternatively a *partial pooling* contract with repayments (r_H^P, r_L^P) that only singles out HH-sellers, and pools the remaining HL-sellers with L-sellers. While the first contract menu generates more information, it requires the lender to leave additional informational rents to sellers by lowering some of the repayments on the initial loan. Lemma 2 characterizes the lender's optimal choice.

Lemma 2. *Suppose that sellers choose offline distribution. Then, the lender offers a separating contract (S) whenever*

$$\lambda \le \lambda_S \equiv (1-\alpha)\frac{\theta - 1}{\theta - p_L}, \tag{2}$$

and a partial pooling contract (P) otherwise. The respective repayments are $r_L^S = (1-\lambda)p_L$, $r_H^S = p_L$, *and* $r_L^P = (1-\lambda)p_L$, $r_H^P = (1-\lambda)p_L + \lambda\theta$.

Inequality (2) captures the trade-off inherent in the lender's screening problem.[13] With full separation, the lender can distinguish HL-sellers from L-sellers. This allows for more efficient re-financing, so that the continuation surplus $\theta - 1$ is not only generated by HH-sellers, but also HL-sellers (conditional on an H-seller arriving, the probability increases by $1-\alpha$). At the same time, separation is costly because the lender must ensure that HL-sellers can afford the high repayment. This requires her to lower the "spread" between high and low repayments from $\lambda\theta$ to λp_L, which is only optimal if λ is sufficiently low.

Sellers' choice of distribution venue. We can now determine sellers' choice of distribution venue at $t = 0$. At this stage, sellers take the contracts derived in the previous section as given. With offline distribution, they will face the separating contract $\{r^S, k^S\}$ or the partially pooling contract $\{r^P, k^P\}$, depending on parameters. By contrast, online distribution implies that they will face the contract $\{r^{\mathcal{D}}, k^{\mathcal{D}}\}$.

Let $M = \{S, P, \mathcal{D}\}$ denote the set of contract menus that sellers can possibly face at $t = 1$, with individual elements indexed by m. Sellers' expected profits for a given venue v and contract menu m are then given by expected sales minus loan repayment plus the gains from the continuation project. This expectation is taken over all possible profiles $\pi = (\tau, p) \in \{H, L\} \times \{p_H, p_L\}$ for this particular venue,[14]

$$S_v^m = E_{\pi|v}\left[p - r^m(\pi) + k^m(\pi)\lambda\theta\right]. \tag{3}$$

Then, using Lemmas 1 and 2, we get expected profits of

$$S_v^m = \begin{cases} \lambda\overline{p}_F + \alpha q(1-\lambda)\Delta_p & \text{if } m = P \text{ and } v = F \quad \text{(a)} \\ \lambda\overline{p}_F + \alpha q(1-\lambda)\Delta_p + q\lambda(\theta - p_L) & \text{if } m = S \text{ and } v = F \quad \text{(b)} \\ \lambda\overline{p}_O & \text{if } m = \mathcal{D} \text{ and } v = O. \quad \text{(c)} \end{cases} \tag{4}$$

With offline (F) distribution, sellers earn informational rents so that their profits exceed their outside option $\lambda\overline{p}_F$. These rents are higher with the separating contract because the bank must lower the "spread" between high and low repayments from $\lambda\theta$ to λp_L to achieve full separation. By contrast, sellers receive exactly their reservation utility with online (O) distribution and $\mathcal{D}$-money. However, we have $\overline{p}_O > \overline{p}_F$ because HL-sellers' generate sales of p_H in this case, compared to p_L with offline distribution. The following Lemma characterizes sellers' venue choice, where λ_S is defined in Eq. (2).

Lemma 3. *Suppose sellers obtain the initial loan. Then, they choose online distribution if one of the following conditions is satisfied.*

(i) $\lambda > \lambda_S$ *and* $\lambda \ge \alpha$

(ii) $\lambda \le \lambda_S$ *and* $\lambda \ge \lambda_0 \equiv \alpha\frac{\Delta_p}{p_H - \theta}$

Otherwise they choose offline distribution.

Sellers' choice trades off the efficiency gains from online distribution with the informational rents arising from the anonymity of offline sales settled in cash. Intuitively, a high value of λ means that sellers obtain a large share of the efficiency gains associated with online distribution, which increases their willingness to choose this venue. By contrast, a high value of α means that the efficiency gains from online distribution are relatively small, so sellers are less willing to sacrifice the informational rents from using cash with offline trade.

To understand this trade-off, it is most instructive to look at the case in which the lender offers a partial pooling contract under offline distribution $(\lambda > \lambda_S)$. Using Eqs. (4)(a) and (4)(c), we can write

$$S_O^{\mathcal{D}} - S_F^P = \lambda(1-\alpha)q\Delta_p - \alpha q(1-\lambda)\Delta_p. \tag{5}$$

The first term of (5) represents the efficiency gains from online distribution that accrues to sellers. Relative to offline distribution, the overall surplus increases by $\overline{p}_O - \overline{p}_F = (1-\alpha)q\Delta_p$ because HL-sellers' sales increase from p_L to p_H. Since the lender is a monopolist, she extracts the maximum surplus possible so that sellers are left with a share λ of these gains. The second term of (5) is the cost of online distribution due to a loss of anonymity. Since the lender obtains a perfect signal, HH-sellers (with mass αq) no longer earn an information rent of $(1-\lambda)\Delta_p$. Canceling terms, we deduce that sellers distribute online if and only if $\lambda > \alpha$.[15]

[13] As usual under monopolistic screening (Bolton and Dewatripont, 2004), the low repayment r_L is pinned down by L-sellers' participation constraint, who just earn their outside option λp_L. The spread between the high and the low repayment is determined by the incentive constraint of HH-sellers for the partial pooling contract, and the feasibility constraint of HL-sellers for the separating contract. While other contracts are possible, we show in the Proof of Lemma 2 that they imply lower expected profits for the lender.

[14] For example, $\pi|O \in \{(H, p_H), (L, p_L)\}$.

[15] The intuition for the case in which the lender offers the separating contract with offline distribution $(\lambda \le \lambda_S)$ is the same. However, sellers' indifference curve is steeper (the slope of λ_0 is larger than one) because they earn more information rents under this contract.

The lender's initial lending decision. We close the model by determining the lender's initial lending decision. She is willing to grant a loan at $t = 0$ if and only if she can at least break even. Note that this can in principle allow for the first loan to be a loss-maker as long as these losses are recouped via the second loan. In equilibrium, the lender correctly anticipates sellers' distribution choice and her own subsequent contract choice. Using Lemmas 1 and 2, we can write the lender's expected profits as

$$\mathcal{L}_v^m = \begin{cases} (1-\lambda)\overline{p}_O - 1 + q(\theta-1) & \text{if } m = \mathcal{D} \text{ and } v = O \quad \text{(a)} \\ (1-\lambda)p_L - 1 + q(\theta-1) - q\lambda(\theta - p_L) & \text{if } m = S \text{ and } v = F \quad \text{(b)} \\ (1-\lambda)p_L - 1 + \alpha q(\theta-1) & \text{if } m = P \text{ and } v = F. \quad \text{(c)} \end{cases} \tag{6}$$

Eq. (6)(a) illustrates that $\mathcal{D}$-money enables the lender to extract the maximum surplus as sellers just obtain their outside option. Our bounds on q and λ ensure that this expression is always positive, so the lender extends the first loan. By contrast, with offline distribution, the lender must cede additional surplus to sellers' for eliciting information. This reduces her profits, such that she may fail to break even if λ is too large (see the Appendix A for the precise thresholds λ_F^S and λ_F^P). In this case, the lender will not extend the initial loan. The following Proposition fully characterizes the equilibrium.

Proposition 1 (*Equilibrium in the Baseline Model*)**.**

1. For $\lambda > \lambda_S$, the lender offers a partial pooling contract to offline sellers. Sellers

(i) distribute online if $\lambda \geq \alpha$,

(ii) distribute offline if $\lambda < \min\{\alpha, \lambda_F^P\}$, and

(iii) do not get an initial loan for $\lambda_F^P < \lambda < \alpha$.

2. For $\lambda \leq \lambda_S$, the lender offers a separating contract to offline sellers. Sellers

(i) distribute online if $\lambda \geq \lambda_0$,

(ii) distribute offline if $\lambda < \min\{\lambda_0, \lambda_F^S\}$, and

(iii) do not get an initial loan for $\lambda_F^S < \lambda < \lambda_0$.

All online sales are settled with $\mathcal{D}$-money (by assumption). The thresholds λ_F^S and λ_F^P are defined in inequalities (A.4) and (A.5) in Appendix A.

Fig. 1 illustrates the equilibrium in the (λ, α)-space. The downward-sloping solid line is $\lambda = \lambda_S$, which represents inequality (2) from Lemma 2. It delineates the parameter combinations for which the lender offers a partially pooling contract (to the right) and a separating contract (to the left) under offline distribution. The two upward-sloping dotted lines represent sellers' indifference curves regarding the choice of trading venue. For parameter combinations above (below), sellers choose online (offline) distribution. Finally, the dash-dotted lines represent the break-even thresholds λ_F^S and λ_F^P. For parameter combinations above these lines, the lender does not extend a loan because she correctly anticipates that this will generate losses.

Overall, the following equilibrium outcomes are possible: (i) no loan, (ii) online distribution, and (iii) offline distribution. To gain intuition, it is helpful to focus on a subset of the parameter space where the contract menu offered by the lender at $t = 1$ (separating or partial pooling) is held fixed.

So consider the area to the left of the solid black line where the lender offers a separating contract. Whenever λ is high relative to α, sellers distribute online because the resulting efficiency gains are large and they are able to extract a sizeable share thereof. Moreover, the use of $\mathcal{D}$-money ensures that the lender is always willing to lend because it guarantees maximum profits. As α increases, sellers' incentives to distribute online diminish and they switch to offline distribution with cash. However, this reduces the lender's profits as she must cede some rents in proportion of λ to extract information on sellers' type. If λ is sufficiently high (above λ_F^S), lending becomes unprofitable and the lender is no longer willing to extend the initial loan.

The intuition for the case when the lender offers a partial pooling contract is essentially the same. The only difference is that this contract entails lower information rents, which slightly alters the trade-offs for sellers' distribution decision (at $t = 1$) and the lender's initial lending decision (at $t = 0$). This can be seen by the differences in slope for the dotted and dash-dotted lines in Fig. 1 across both sides of the solid line.

The equilibrium is efficient whenever sellers distribute goods online (see the white areas in Fig. 1). In this case, all H-sellers generate high sales p_H. Moreover, the use of $\mathcal{D}$-money ensures that the lender becomes fully informed and provides a continuation loan to all H-sellers (and only them). The total surplus generated in this case is given by

$$\mathcal{W}_O = \overline{p}_O - 1 + q(\theta - 1). \tag{7}$$

Otherwise, the equilibrium is inefficient, which is indicated by gray and shaded areas in Fig. 1. Since sellers do not abscond on the equilibrium path, three inefficiencies arise in equilibrium. First, offline distribution entails a welfare loss of $(1-\alpha)q\Delta_p$ because HL-sellers generate low revenues. Second, an additional inefficiency arises when the lender uses the partial pooling contract. In this case, she fails to provide continuation financing to HL-sellers, which generates a welfare loss of $(1-\alpha)q(\theta-1)$. Finally, whenever the lender decides not to grant the initial loan, no output is generated at all and total welfare is equal to zero.

$$\mathcal{W}_F^S = \mathcal{W}_O - (1-\alpha)q\Delta_p \tag{8}$$

$$\mathcal{W}_F^P = \mathcal{W}_O - (1-\alpha)q\Delta_p - (1-\alpha)q(\theta-1) \tag{9}$$

$$\mathcal{W}_{NL} = 0. \tag{10}$$

Accordingly, we can rank equilibrium outcomes in terms of welfare as follows: $\mathcal{W}_O > \mathcal{W}_F^S > \mathcal{W}_F^P > \mathcal{W}_{NL}$.

4. Alternative arrangements

In this section, we study two deviations from the benchmark model. These are motivated by recent developments such as the rise of non-bank payment service providers (PSPs), the advent of new technologies (e.g. blockchain), regulatory initiatives like "open banking", and the ongoing debate on central bank digital currency (CBDC). First, we study the case of privacy-preserving digital payments that prevent the lender from extracting information from payment flows. Second, we analyze a model where end-users have control over the data generated by payment systems, and can decide whether and with whom to share them.

4.1. Privacy-preserving digital payments

The past two decades have seen the rapid rise of non-bank PSPs, including firms like Paypal (United States), Wise (United Kingdom), WeChat Pay and AliPay (China). While payments continue to be settled in commercial bank money held in segregated accounts, these entities provide the customer interface for an increasing number of transactions. This implies that they are in control over the data that is being generated through individual payments. Accordingly, banks merely provide the payment rails and often only observe netted payment flows after individual transactions have been internalized within the PSPs' systems. Moreover, these transactions frequently come without information on their ultimate origin and purpose. Taken together, the growth of non-bank PSPs implies a significant loss on banks' ability to derive information from payment flows.

Going forward, technological innovations also have the potential to diminish banks' ability to derive information from payments data. The central premise of distributed ledger technology (DLT) is the decentralized settlement of transactions in the digital space. By definition, this aims to eliminate the creation of an informative digital footprint. While cryptocurrencies are currently not widely adopted as means of payment, DLT has the potential to further disrupt the information flows to banks and other lenders.

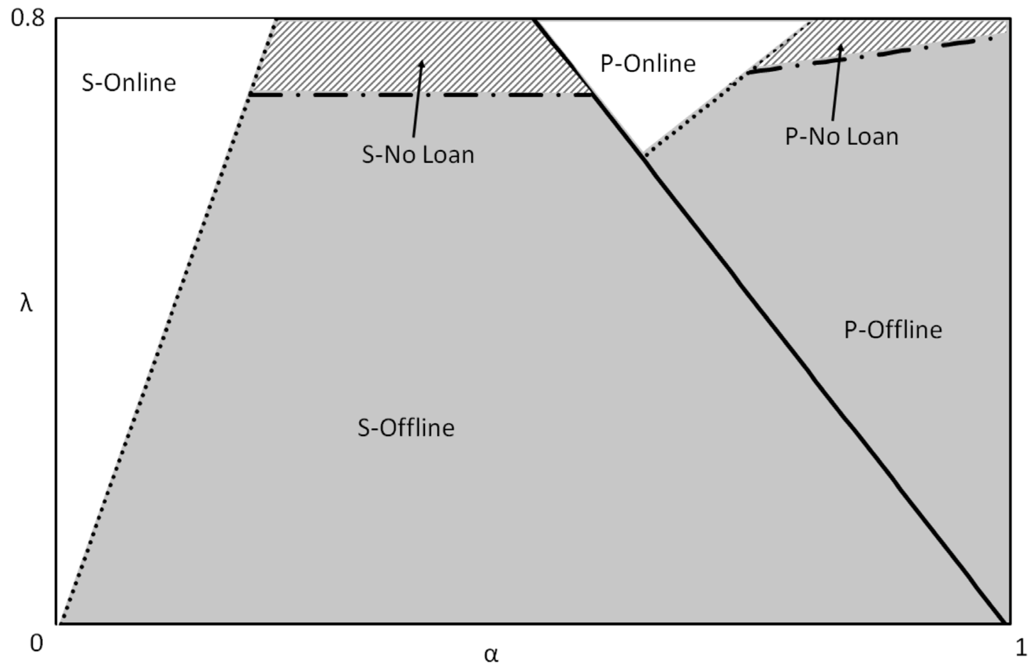

Fig. 1. Equilibrium Map with $\mathcal{D}$-money in (α, λ)-space. Parameter values are: $p_H = 6$, $p_L = 2.5$, $\theta = 5$, $q = 0.11$. The y-axis is truncated at $\overline{\lambda} = 0.8$. Since $q\theta < 1$, $\underline{\lambda} = 0$. Labels indicate (i) the type of contract menu offered by the lender conditional on sellers choosing offline distribution, and (ii) the equilibrium outcome (Online, Offline, No Loan). For example, the label "S-Online" indicates that the lender offers a separating contract under offline distribution, and sellers choose to distribute online in equilibrium.

Finally, central banks around the world are examining the case for retail CBDC. Several major central banks have made pledges to incorporate privacy-preserving features into their CBDC designs, which is likely to reduce the informational content of payment flows relative to the status quo with $\mathcal{D}$-money.[16] The People's Bank of China (PBOC) has already rolled out its e-CNY across several major cities, and its privacy provisions imply a drastic loss of access to information for banks.[17]

With these developments in mind, we modify our benchmark model and henceforth assume that digital payments are based on privacy-preserving technology. We refer to this as $\mathcal{P}$-money. Again for simplicity, we assume that such payments generate a completely uninformative signal, so $x = \frac{1}{2}$. Recall that Online Appendix OA.1 considers the case with general precision $x \in [\frac{1}{2}, 1]$.

Whenever sellers distribute online and allow sales to be settled in $\mathcal{P}$-money, the lender faces a similar problem as with offline sales settled in cash.[18] Since the signal is uninformative, she must elicit information by setting the appropriate contractual terms on the initial loan. However, since online distribution is efficient, all H-sellers generate high sales, p_H. This simplifies the lender's inference problem.

Lemma 4. *Suppose that sellers choose online distribution and settlement in $\mathcal{P}$-money. Then, the lender always offers a separating contract with repayments $r_H^{\mathcal{P}} = (1-\lambda)p_L + \lambda\theta$ and $r_L^{\mathcal{P}} = (1-\lambda)p_L$.*

Given these contract terms, sellers' expected payoff under online distribution with $\mathcal{P}$-money is equal to

$$S_O^{\mathcal{P}} = \lambda \overline{p}_O + q(1-\lambda)\Delta_p. \tag{11}$$

In this case, all H-sellers generate high sales and earn an informational rent of $(1-\lambda)\Delta_p$. Comparing this payoff with Eqs. (4)(a)–(4)(c) yields the following result regarding sellers' optimal venue choice.

Lemma 5. *Define $\widehat{\lambda} \equiv (1-\alpha)\frac{\Delta_p}{\theta - p_L}$ and suppose sellers obtain the initial loan. Then, they choose offline distribution if and only if $\widehat{\lambda} < \lambda < \lambda_S$. All online payments are settled in $\mathcal{P}$-money.*

Relative to the benchmark case where sellers must choose between cash and $\mathcal{D}$-money, the introduction of $\mathcal{P}$-money enables sellers to capture the best of both worlds. They can reap the efficiency gains of online distribution, as well as the informational rents from remaining anonymous vis-a-vis the lender. As a result, $\mathcal{P}$-money fully displaces $\mathcal{D}$-money.

Interestingly, physical cash continues to play a role in the economy with $\mathcal{P}$-money. This is the case whenever sellers prefer to distribute offline, which requires two conditions. First, the lender must choose to offer a separating contract with offline distribution, which yields higher informational rents for sellers than the partial pooling contract. This requires $\lambda \leq \lambda_S$. Second, sellers must prefer this option over online distribution with $\mathcal{P}$-money, which is the case for $\lambda \geq \widehat{\lambda}$. The following inequality ensures that $\lambda_S > \widehat{\lambda}$, so that both conditions can be fulfilled simultaneously. Going forward, we assume that it is satisfied.

Assumption 4. $\theta - 1 > \Delta_p$.

The lender's expected profit is

$$\mathcal{L}^{\mathcal{P}} = (1-\lambda)p_L - 1 + q(\theta - 1), \tag{12}$$

which is non-negative for $\lambda \leq \lambda^{\mathcal{P}} \equiv \frac{p_L - 1 + q(\theta-1)}{p_L}$. Together with Lemmas 2 and 5, we can now characterize the equilibrium in the economy with $\mathcal{P}$-money.

[16] For example, the Bank of England recently launched a new consultation paper, according to which CBDC users would be able to "vary their privacy preferences to suit their privacy needs" (Bank of England, 2023b).

[17] See Duffie and Economy (2022) for a detailed description. They write (p.32): "Within the e-CNY system, operating institutions cannot directly see who is paying whom or even how much is being paid because the PBOC's authentication center verifies the authenticity of circulating e-CNY, not the operating institutions".

[18] We do not consider the case of offline sales settled in $\mathcal{P}$-money because the only feature that distinguishes them from cash is their ability to settle online transactions.

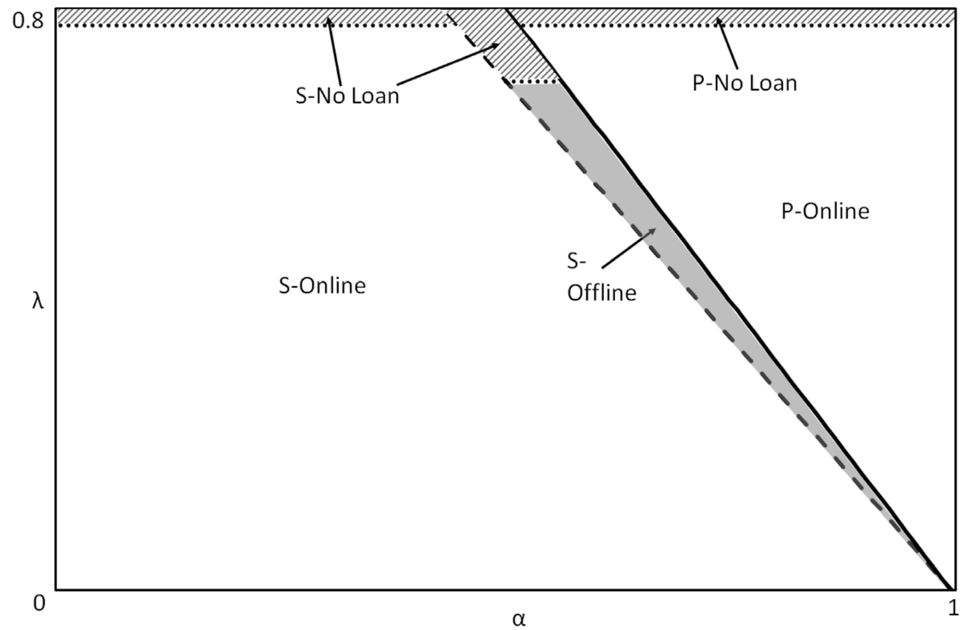

Fig. 2. Equilibrium Map with $\mathcal{P}$-money in (α, λ)-space. Parameter values are: $p_H = 6$, $p_L = 2.5$, $\theta = 5$, $q = 0.11$. The y-axis is truncated at $\overline{\lambda} = 0.8$. Since $q\theta < 1$, $\underline{\lambda} = 0$. Labels indicate (i) the type of contract menu offered by the lender conditional on sellers choosing offline distribution, and (ii) the equilibrium outcome (Online, Offline, No Loan). For example, the label "S-Online" indicates that the lender offers a separating contract under offline distribution, and sellers choose to distribute online in equilibrium.

Proposition 2 (*Equilibrium with $\mathcal{P}$-Money*).
1. For $\lambda_S < \lambda$, the lender offers a partial pooling contract to offline sellers. Sellers distribute online for $\lambda \leq \lambda^{\mathcal{P}}$, and do not get an initial loan otherwise.
2. For $\hat{\lambda} < \lambda < \lambda_S$, the lender offers a separating contract to offline sellers. Sellers distribute offline for $\lambda \leq \lambda_F^S$, and do not get an initial loan otherwise.
3. For $\lambda < \hat{\lambda}$, the lender offers a separating contract to offline sellers. Sellers distribute online for $\lambda \leq \lambda^{\mathcal{P}}$, and do not get an initial loan otherwise.
All online sales are settled with $\mathcal{P}$-money.

Fig. 2 illustrates the equilibrium. There are two downward-sloping diagonal lines which separate the parameter space into three regions that correspond to the different cases listed in Proposition Proposition 2. As before, the solid line $\lambda = \lambda_S$ delineates the parameter space for which the lender offers a partially pooling contract (to the right) and a separating contract (to the left) under offline distribution. In addition, the dashed line $\lambda = \hat{\lambda}$ indicates the parameter combinations for which sellers are indifferent between online distribution with $\mathcal{P}$-money and offline distribution with cash when the lender offers a separating contract. Following Assumption 4, we have $\hat{\lambda} < \lambda_S$, so this line is to the left of the solid line, and the space between both lines represents the parameter space where sellers prefer offline distribution.

To gain some intuition, fix some point in the "S-Online" region and move horizontally by increasing α while keeping λ fixed. As α increases, offline distribution becomes more attractive, and sellers prefer to switch once the threshold $\hat{\lambda}$ is crossed. As α increases further, the lender finds it less worthwhile to engage in full separation and opts for a partial participation contract instead once the second threshold λ_S is crossed. However, the resulting decrease in sellers' informational rents induces them to switch back to online distribution.

The horizontal dotted lines represent the thresholds λ_F^S and $\lambda^{\mathcal{P}}$ above which the lender is not willing to grant the initial loan. We observe that $\lambda^{\mathcal{P}} > \lambda_F^S$, i.e. it is more difficult for lenders to break even when sellers choose the offline venue. This is intuitive: in order to achieve full separation with cash, the lender must offer larger informational rents. Moreover, the total surplus generated is lower than with online distribution.

Comparing Propositions 1 and 2 allows us to study the welfare effects of an introduction of $\mathcal{P}$-money relative to the benchmark economy with $\mathcal{D}$-money. We have the following result.

Corollary 1 (*Relative Efficiency of $\mathcal{D}$- and $\mathcal{P}$-Money*).
(i) For $q \leq q^* \equiv \frac{\theta - p_L}{\theta(\theta-1)}$, we have $W^{\mathcal{P}} \leq W^{\mathcal{D}}$ whenever $\lambda \geq \lambda^{\mathcal{P}}$, and $W^{\mathcal{P}} \geq W^{\mathcal{D}}$ otherwise.
(ii) For $q > q^*$, we always have $W^{\mathcal{P}} \geq W^{\mathcal{D}}$.

Importantly, online distribution generates the same total surplus W_O (see Eq. (7)) for both types of money. Accordingly, any differences in welfare can only arise from their effects on lending decisions or venue choices.

We highlight three channels affecting welfare. The first two effects ensure that the introduction of $\mathcal{P}$-money tends to raise welfare whenever λ is relatively low and sellers tend to opt for offline distribution in the benchmark economy. First, the availability of $\mathcal{P}$-money improves sellers' incentives to opt for online distribution, in which case all H-sellers generate high sales p_H. Second, with $\mathcal{P}$-money, there is no longer an equilibrium with offline sales *and* a partial pooling contract. This implies that the lender's continuation investment choice is now always efficient, conditional on the extension of an initial loan.

The third channel of introducing $\mathcal{P}$-money however reduces welfare for high values of λ. Indeed, the use of $\mathcal{P}$-money re-distributes surplus from the lender to sellers. If this effect is sufficiently strong so that $\lambda^{\mathcal{P}} < \overline{\lambda}$ (or equivalently $q < q^*$), the lender will refuse to grant the initial loan, and no surplus is generated. Finally, we note that $\mathcal{D}$-money and $\mathcal{P}$-money lead to the same equilibrium outcome for $\lambda \in [\hat{\lambda}, \lambda_S]$, namely offline distribution with a separating contract. In this case, there is no welfare difference between $\mathcal{D}$- and $\mathcal{P}$-money.

4.2. Digital payments with data-sharing/user-control

The previous section has shown that the introduction of $\mathcal{P}$-money can increase efficiency relative to a world with only cash and $\mathcal{D}$-money. However, even when the initial loan is granted, the equilibrium is not always efficient because the informational rents associated with cash can be too large to induce sellers to switch to online distribution. In this section, we ask whether efficiency can be improved by providing sellers with some form of control over their payments data.

This idea is based on a host of recent regulatory initiatives known under the umbrella term "open banking". In a nutshell, open banking aims to enable users to share their payments data with third parties in order to enhance competition and innovation in the provision of financial services (He et al., 2023; Babina et al., 2024). While much of the related debate has focused on consumers, it is also relevant for firms, in particular small businesses.[19] However, open banking is still far from "full" control since these regulations do not prevent the original institution from observing the data when they are generated, thus still giving it a competitive (first-mover) advantage.

Recent advances in technology allow us to envisage a system where users are in complete control of their data. One concrete example is "India Stack", an infrastructure project that is transforming the payment ecosystem in India. It comprises digital ID, interoperable digital payments, and user consent.[20] The last element (consent) is guaranteed by the existence of so-called "fiduciaries" that intermediate the flow of financial data between individuals and financial firms. These fiduciaries are responsible for managing personal data, and must obtain an individual's consent before processing it. They may not access or store shared data, but can charge a fee for their services (see Carriere-Swallow et al., 2021).

Similarly, the design of CBDCs may include significant elements of end-user control. Several major central banks made statements in this direction. In particular, they emphasize that user consent will likely be a prerequisite for intermediaries to obtain access to payments data.[21]

Given these developments, we study the implications of digital payments with end-user control in our model. This is consistent with a broader concept of privacy that goes beyond the dimension of anonymity, as summarized succinctly by Acquisti et al. (2016): "Privacy is not the opposite of sharing—rather it is control over sharing".[22] We refer to such payments as $\mathcal{C}$-money (where $\mathcal{C}$ refers to user "control"). Specifically, we assume that sellers can choose whether they want the lender to receive a signal (i.e. they choose $x \in \{\frac{1}{2}, 1\}$), and whether this signal is revealed *before* or *after* the repayment of the initial loan. This extent of user-control implies that the lender can no longer monitor sellers' payments activity in real time even in case they choose to disclose the signal after repayment. Accordingly, sellers are able to abscond successfully without the need for offshore accounts or opaque accounting procedures. Hence, the signal's informativeness is preserved when it is released to the lender, even in the case sellers decide to abscond.

The ability to exert data control via $\mathcal{C}$-money has profound consequences for the equilibrium in the lending market at $t = 1$. In particular, it prevents the lender from "screening" because incentive compatibility breaks down. Since H-sellers can reveal their type truthfully and at zero cost (using the payments record) *after* the repayment of the initial loan, they have no incentive to incur any but the lowest possible repayment. By contrast, L-sellers still have an incentive to pretend being H-sellers and abscond with the second loan. Together, this makes it impossible for lender to separate types.[23] Hence a separating contract is infeasible, and the lender can only offer a pooling contract with interest rate $\bar{r}^{C} = (1-\lambda)p_L$. Therefore, sellers' ex-ante expected payoff is given by

$$\mathcal{S}_O^C = \lambda \overline{p}_O + q[(1-\lambda)\Delta_p + \lambda\theta], \tag{13}$$

where $\mathcal{S}_O^C$ indicates the use of $\mathcal{C}$-money with online distribution. Comparison with Eqs. (4)(a)–(4)(c) and (11) reveals that this payoff is strictly larger than those associated with any other payment means. Hence, conditional on receiving the initial loan, sellers always opt for online distribution with $\mathcal{C}$-money.

The associated expected profit to the lender is

$$\mathcal{L}^C = (1-\lambda)p_L - 1 + q[(1-\lambda)\theta - 1], \tag{14}$$

where the first two terms are the surplus from the first loan, while the last term represents the profits from lending to H-sellers for the second round of production. This expression is non-negative for $\lambda \le \lambda^C \equiv \frac{p_L - 1 + q(\theta-1)}{p_L + q\theta}$. We can summarize this discussion as follows.

Proposition 3 (*Equilibrium with $\mathcal{C}$-Money*).

Sellers receive an initial loan and distribute online for $\lambda \le \lambda^C$. Otherwise they do not receive an initial loan. Only H-sellers receive a continuation loan. All online sales are settled with $\mathcal{C}$-money.

The use of $\mathcal{C}$-money enables sellers to separate the bright side (generating continuation finance) and the dark side of informative payment flows (rent extraction). Since they can delay the release of the signal until after the initial repayment, the lender is no longer able to appropriate the full continuation surplus through the first loan. Once the repayment is carried out, H-sellers are happy to reveal the signal in order to reap a share λ of the additional surplus generated by the continuation loan. L-sellers would prefer to hide their identity, but they cannot since H-sellers prefer to reveal theirs.[24]

Corollary 2 (*Relative Efficiency of $\mathcal{P}$- and $\mathcal{C}$-Money*).

We have $W^C \le W^P$ for $\lambda \ge \lambda^P$, and $W^C \ge W^P$ otherwise.

Relative to the economy with $\mathcal{P}$-money, $\mathcal{C}$-money generates additional efficiency gains by fully crowding out offline distribution settled with cash, which ensures that the level of initial sales is always efficient. However, at the same time, $\mathcal{C}$-money re-distributes even more surplus from the lender to sellers. This lowers the break-even threshold from λ^P to λ^C, and thus increases the range of parameters for which no surplus at all is generated because the lender refuses to extend the initial loan.

5. Optimal payment instruments

In this section, we extend the model by studying a social planner's ex-ante choice of payment instrument. To this end, we assume that λ is not constant, but instead the realization of a random variable $\tilde{\lambda}$ with cumulative distribution function $F(\lambda)$ defined over the interval $(\underline{\lambda}, \overline{\lambda})$. While λ is realized at the beginning of $t = 0$ (so all of our previous calculations continue to apply for a realized λ), the planner chooses the available digital payment instrument at $t = -1$ from the set $\{\mathcal{D}, \mathcal{P}, \mathcal{C}\}$ to

[19] For example, a recent report by Moody's states: "Open Banking is transforming the SME lending landscape by shifting ownership of transactional data from banks to the firms themselves, granting SMEs access and control of their own data". See https://www.moodys.com/web/en/us/insights/banking/open-banking-real-time-analytics-for-small-and-medium-sized-enterprises.html. The webpage of "Open Banking Limited", a non-profit body in the UK tasked with the implementation of standards and systems at the request of the UK Competition and Markets Authority, contains a wide range of short articles and guides aimed at informing SMEs, such as "Open banking for small businesses – a quick guide" (available at https://www.openbanking.org.uk/insights/open-banking-for-small-businesses-a-quick-guide/).

[20] See https://indiastack.org for details.

[21] A recent report by the European Central Bank states: "Digital euro users would have full control over how their own personal data are used". European Central Bank (2023). The Bank of England has communicated: "Digital pound users will be able to make choices about the way their data is used. We are supportive of, and encourage, firms to offer services that enable holders to opt for enhanced privacy functionality and exert greater user control of personal data". Bank of England (2023a)

[22] In a similar vein, Hughes (1993) argues that "Privacy is the power to selectively reveal oneself to the world".

[23] Formally, a separating contract (r_H^C, r_L^C), must satisfy the following ICs

$$p_H - r_H^C + \lambda\theta \ \ge\ p_H - r_L^C + \lambda\theta$$
$$p_L - r_L^C \ \ge\ p_L - r_H^C + \lambda.$$

In essence, $\mathcal{C}$-money enables H-sellers to obtain a share of the surplus of the second loan even upon absconding. These constraints imply $0 \ge r_H^C - r_L^C \ge \lambda$, a contradiction.

[24] A seller hiding his identity reveals he is of type L.

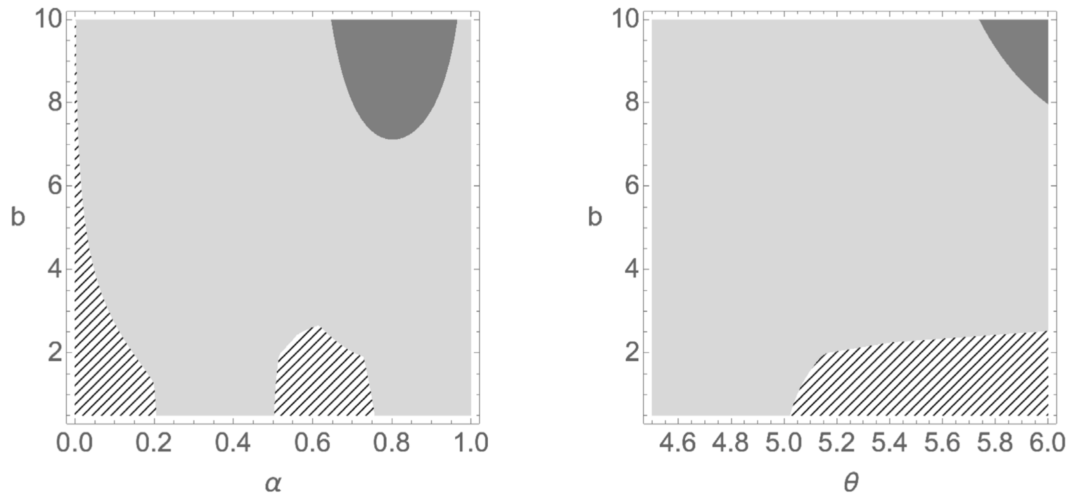

Fig. 3. This figure shows how the planner's optimal choice $\mathcal{M}^*$ depends on parameters. The areas with hashed lines represent $\mathcal{D}$-money, the light gray areas represent $\mathcal{P}$-money, and the dark gray areas represent $\mathcal{C}$-money. In Panel A (LHS), the parameter values are: $p_H = 6$, $p_L = 2.5$, $\theta = 5$, $q = 0.11$. In Panel B (RHS), the parameter values are: $p_H = 6$, $p_L = 2.5$, $q = 0.11$, $\alpha = 0.5$.

maximize utilitarian welfare. We assume that cash is always available. Formally, the planner solves

$$\max_{\mathcal{M}\in\{\mathcal{D},\mathcal{P},\mathcal{C}\}} \int_{\underline{\lambda}}^{\overline{\lambda}} \mathcal{W}^{\mathcal{M}}(\lambda) dF(\lambda), \tag{15}$$

where $\mathcal{W}^{\mathcal{M}}(\lambda)$ is the equilibrium surplus in the economy with $\mathcal{M}$-money for $\tilde{\lambda} = \lambda$.

Since this problem is analytically intractable, we solve it numerically. We assume that λ is drawn from a beta distribution $\mathfrak{B}(a, b)$ with shape parameters a and b. We fix $a = 3$ throughout, and let b take values in the interval $[0.25, 10]$. Recall from Assumption 2 that $\lambda \in (\underline{\lambda}, \overline{\lambda})$. Accordingly, we truncate the probability density function so that only values from this interval can be drawn.

Fig. 3 illustrates how the welfare-maximizing choice $\mathcal{M}^*$ depends on the model's parameters. In both panels, the y-axis represents the shape parameter b. For a $\mathfrak{B}(a, b)$ distribution, an increase in b shifts mass to the left, so that lower values of λ are becoming more likely. The x-axis represents the relative efficiency of offline distribution, α, in Panel A (LHS), and the size of the continuation surplus, θ, in Panel B (RHS). As the Figure shows, each type of digital money can be the ex-ante optimal choice for at least some parameter combinations.

We first discuss Panel A (LHS). First, we see that $\mathcal{D}$-money (area with hashed lines) is the optimal choice when (i) α is not too high and (ii) b is relatively low (i.e. higher values of λ are more likely). We have shown in the previous two sections that, conditional on the first loan being granted, such a parameter constellation will induce sellers to opt for online distribution with all types of digital money. Since the loan market never breaks down with $\mathcal{D}$-money (unlike with $\mathcal{P}$- or $\mathcal{C}$-money), it is the optimal choice in this case. As α increases, it ceases to be optimal because of the increased incentives for sellers to stay offline.[25]

Second, $\mathcal{C}$-money is optimal for high (but not too high) values of α and b (so low values of λ are more likely), as shown by the dark shaded area. This is consistent with Fig. 2, which shows that sellers prefer cash to $\mathcal{P}$-money when α is in this range. At the same time, a high weight on low values of λ ensures that the likelihood of a loan market breakdown with $\mathcal{C}$-money is not too severe, so that it is the optimal choice. For the remainder of the parameter space (the gray area), $\mathcal{P}$-money is the optimal choice, as it strikes a balance between the provision of incentives for online distribution and the risk of a loan market breakdown.

The intuition from Panel B (RHS) is similar. For sufficiently high values of the continuation surplus θ, the optimal design of digital money depends on the shape of the distribution function $F(\lambda)$. When b is high (so low values of λ are more likely), $\mathcal{C}$-money is optimal because it enables sellers to capture at least part of the continuation surplus. By contrast, a low b (high values of λ) can give rise to a loan market breakdown, and the potential loss in output is larger for higher values of θ. Then, $\mathcal{D}$-money is optimal. $\mathcal{P}$-money strikes a balance between these two effects and is thus optimal for intermediate values of b. Whenever θ is low, this trade-off disappears as the welfare effects related to θ are diminishing.

While our model is deliberately abstract, some policy implications can be derived by mapping the key parameters to real-world observables. Our discussion focuses on the role of cross-country differences because payments are typically regulated at the national level. One key parameter is λ, which represents sellers' bargaining position via-à-vis the lender (captured through the threat of absconding). Two interpretations come to mind: (i) competition in lending markets, and (ii) moral hazard frictions related to the enforcement of financial contracts. We discuss the implications for both views in turn.

First, λ may reflect the degree of competition in national lending markets, e.g. as measured by the Herfindahl–Hirschman index (HHI). In more competitive markets characterized by high values of λ, borrowers face a lower cost of credit (see, e.g., Sapienza, 2002; Beck et al., 2004; Degryse and Ongena, 2005) which enables them to extract a higher share of the surplus from their projects. This helps to reach efficient outcomes by aligning private and social incentives. Our model implies that countries with a very competitive banking system should be wary of fostering the adoption of digital payment instruments with privacy features because the resulting pressure on banks' profit margins may lead to a decline in the volume of credit. By contrast, countries with a concentrated banking system will be better off by fostering the adoption of privacy enhancement in the payments space, including policies such as "open banking".

Second, λ may represent the (non-pecuniary) costs of enforcing financial contracts (as in e.g. Mendoza et al., 2009; Castro et al., 2004).[26] Our model suggests that countries with less-developed legal systems (represented by a high value of λ) may not benefit from privacy

[25] The second region where $\mathcal{D}$-money is optimal (for intermediate values of α) arises as the lender switches from a separating to a pooling contract, where relatively high values of λ again give rise to online distribution, as shown in Fig. 1.

[26] Similarly, λ could also reflect cross-country differences in the availability of collateral.

enhancements in payments. Since lending markets are already underdeveloped due to moral hazard frictions, a redistribution of surplus away from lenders will put further strain on the provision of credit.

Another key parameter is α, which captures the efficiency level of offline distribution (relative to online distribution). Again, different interpretations are possible. For example, α may represent the exposure of different economic sectors to innovations in digital distribution, such as tradable (low α) vs. non-tradable (high α) goods and services. Alternatively, it may capture broader levels of economic efficiency across economies, as this is directly related to the expected efficiency gains of technology adoption. Along these lines, high values of α could represent advanced economies, while low values of α would represent emerging market economies. Following this interpretation, our model would imply that emerging economies would benefit more from privacy enhancements in the payments space because they have relatively more to gain from aligning private and social incentives in technology adoption. However, this would have to be weighed against the above-mentioned enforcement frictions.

The parameter α also relates to the structure of markets. Low values of α could represent economies with a large informal sector where it is more difficult to advertise products. Empirically (see e.g. Johnson et al., 1998), the presence of a large informal sector (an offline market with a low α) tends to go hand in hand with low levels of enforcement (a high λ). For such economies, our model shows that $\mathcal{D}$-money is optimal.

Finally, the parameter θ represents future product demand. Empirically, this could relate to cross-country variation in growth opportunities, driven by differences in sectoral composition (e.g. growth vs. value sectors), productivity, or demographic conditions. Our analysis suggests that for countries with relatively lower growth potential (e.g. mature economies with low productivity growth), $\mathcal{P}$-money is the optimal choice. By contrast, for high-growth economies, the optimal design of digital money depends on the level of λ (e.g. banking sector concentration or the ease of contract enforcement).

6. Conclusion

Our model provides a tractable framework for thinking about the interconnections between payments and privacy in the digital economy. In its most basic version, the model is centered around a simple trade-off: digital payments facilitate the efficient distribution of goods via online channels, but they entail a costly loss in privacy because they leave a digital footprint. Sufficiently large privacy concerns (endogenously derived from first principles) then lead to welfare losses because of inefficient goods distribution and suboptimal investment.

In this setting, digital payment means that preserve privacy or allow for end-user control over data can improve welfare because they enable sellers to get the best of both worlds: they can remain anonymous when it matters, reveal their type when they need it, and still reap the benefits of distributing goods online. However, the concomitant re-distribution of rents from the lender to sellers can be "too large" and induce a breakdown of the lending market. Accordingly, the socially optimal choice of available payment instruments is ambiguous.

Our paper has important implications for the regulation of payment systems and the optimal design of private and public digital money. Our findings suggest that laissez-faire may entail welfare losses, and regulations such as "open banking" (and further steps towards "full" user control) can help alleviate privacy concerns because they help level the playing field. However, we also highlight the "perils of control", since tilting the balance too much from lenders towards end-users creates the risk of credit rationing. Accordingly, the optimal design of digital money depends on the economic environment, including factors such as competition in lending markets, the legal system, and the sectoral structure of the economy.

While most of the discussion on privacy and payments focuses on customers, our paper places a novel emphasis on the privacy of merchants. As our paper exemplifies, there are good reasons to think this is also an important aspect of payment system design that regulators and central banks should consider seriously.[27]

CRediT authorship contribution statement

Toni Ahnert: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Peter Hoffmann:** Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Cyril Monnet:** Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Proofs

Proof of Lemma 1. When $\mathcal{D}$-money (deposits) is used under online distribution, the lender receives a perfect signal about actual sales ($x = 1$), which directly reveals sellers' types. Thus, no ICs are needed and the relevant PCs are

$$p_H - r_H^{\mathcal{D}} + \lambda\theta \geq \lambda p_H$$
$$p_L - r_L^{\mathcal{D}} \geq \lambda p_L,$$

where we have used the fact that absconding requires a scrambling of the payment signal, so that the lender cannot extend a continuation loan to a H-seller who absconds because uninformed lending is unprofitable, $(1-\lambda)q\theta < 1$. Profit maximization implies that each of these PCs bind, resulting in the repayment stated in the Lemma. Feasibility is ensured by Assumption 1. The lender's expected profit is

$$\begin{aligned}\mathcal{L}_O^{\mathcal{D}} &= q(r_H^{\mathcal{D}} - 1) + (1-q)(r_L^{\mathcal{D}} - 1) + q\left[(1-\lambda)\theta - 1\right] \\ &= (1-\lambda)p_L - 1 + q(\theta - 1) + q(1-\lambda)\Delta_p > 0. \end{aligned} \tag{A.1}$$

Positive expected profits to the lender arises because the lower bound in Assumption 3, $q > \underline{q}$, whenever $\lambda < \overline{\lambda}$. More formally, the critical value of λ at which $\mathcal{L}_O^{\mathcal{D}} \equiv 0$ exceeds $\overline{\lambda}$ whenever $q > \underline{q}$.

Proof of Lemma 2. First, consider the *separating contract*. Since the lender provides re-financing to all H-sellers, incentive compatibility requires that they both choose the high repayment r_H^S. Hence, the contract must satisfy the following simplified ICs:

$$p_H - r_H^S + \lambda\theta \geq p_H - r_L^S$$
$$p_L - r_H^S + \lambda\theta \geq p_L - r_L^S$$
$$p_L - r_L^S \geq p_L - r_H^S + \lambda,$$

because pretending to have high sales by paying r_H^S yields a continuation loan, which is worth λ to an L-seller (who can abscond with the loan at $t = 2$).

Uninformed lending is again unprofitable, so a seller who absconds does not obtain a loan. Hence, the participation constraints (PCs) are

$$p_H - r_H^S + \lambda\theta \geq \lambda p_H,$$
$$p_L - r_H^S + \lambda\theta \geq \lambda p_L,$$

[27] Several central banks, such as the European Central Bank and the Bank of England have floated the idea of holding limits for CBDCs (see, e.g. European Central Bank, 2023; Bank of England, 2023b). Transactions exceeding these limits would be transferred automatically (or "swept") into ordinary bank accounts. Low holding limits would imply that the payment flows observable to banks remain relatively informative, so that not all potential welfare benefits from enhanced privacy are realized.

$$p_L - r_L^S \geq \lambda p_L.$$

The first PC must be slack because the second PC is more restrictive. Moreover, feasibility requires that sellers have enough funds for repayment at $t = 1$,

$$p_H \geq r_H^S, \quad p_L \geq r_H^S, \quad p_L \geq r_L^S.$$

Clearly, only the second feasibility constraint can be binding in equilibrium.

Under profit maximization, the last PC binds, $r_L^S = (1-\lambda)p_L$. Substitution into either of the first two ICs or the second PC (they have identical implications) yields $\lambda\theta + (1-\lambda)p_L \geq r_H^S$. By Assumption 1, all of these three constraints are slack. As a result, the second feasibility constraint must bind, so we have $r_H^S = p_L$. Note that the third IC (the one for the L-seller) is also satisfied because $p_L \geq 1$ (Assumption 1). The lender earns

$$\begin{aligned}\mathcal{L}_F^S &= q(r_H^S - 1) + (1-q)(r_L^S - 1) + q\,[(1-\lambda)\theta - 1] \\ &= (1-\lambda)p_L - 1 + q(\theta - 1) - q\lambda(\theta - p_L). \qquad \text{(A.2)}\end{aligned}$$

Second, consider the *partial pooling contract*, under which the lender only extends continuation finance to HH-sellers (H-sellers with high sales). Since HL-sellers do not obtain re-financing, they must optimally choose the low repayment r_L^P. Hence, the simplified ICs read

$$\begin{aligned}p_H - r_H^P + \lambda\theta &\geq p_H - r_L^P, \\ p_L - r_L^P &\geq p_L - r_H^P + \lambda\theta, \\ p_L - r_L^P &\geq p_L - r_H^P + \lambda.\end{aligned}$$

Pretending to have high sales by paying r_H^P yields a continuation loan, which is worth $\lambda\theta$ to an HL-seller (who can abscond with future production at $t = 3$) and λ to an L-seller (who can abscond with the loan at $t = 2$). The first two ICs directly yield $r_H^P = r_L^P + \lambda\theta$. The contract must also satisfy the following PCs.

$$\begin{aligned}p_H - r_H^P + \lambda\theta &\geq \lambda p_H, \\ p_L - r_L^P &\geq \lambda p_L, \\ p_L - r_L^P &\geq \lambda p_L.\end{aligned}$$

Profit maximization yields $r_L^P = (1-\lambda)p_L$, so $r_H^P = (1-\lambda)p_L + \lambda\theta$. Assumption 1 ensures that the contract is feasible. Lender profits under partial pooling are

$$\begin{aligned}\mathcal{L}_F^P &= \alpha q(r_H^P - 1) + (1-\alpha q)(r_L^P - 1) + \alpha q\,[(1-\lambda)\theta - 1] \\ &= (1-\lambda)p_L - 1 + \alpha q(\theta - 1). \qquad \text{(A.3)}\end{aligned}$$

Comparing Eqs. (A.2) and (A.3) yields $q(1-\alpha)(\theta-1) \geq q\lambda(\theta - p_L)$, which can be expressed as the inequality in Lemma 2.

A (fully) *pooling contract* would imply a repayment $\bar{r} = (1-\lambda)p_L$ for all sellers and thus yield strictly lower lender profits than the contracts characterized above. Intuitively, the lender learns nothing under full pooling, so a continuation loan is never granted and the lender never reaps future surplus.

Finally, consider a *partial participation contracts*, whereby L-sellers default and abscond but the seller can extract more surplus from H-sellers. There are two cases: (a) only HH-sellers participate and HL-sellers also default and abscond; and (b) all H-sellers participate. We consider these cases in turn and show that they yield a lower expected profit to the lender than at least one of the previous contracts (separation or partial pooling) because of a small share of H-sellers (Assumption 3).

Note that a single repayment is offered under partial participation, so there are no ICs. In case (a), the PC of HH-sellers binds, so $r^{PP,a} = (1-\lambda)p_H + \lambda\theta$, which is feasible because of Assumption 1. Since the share of HH-sellers is αq, the expected profit of the lender is $\alpha q[r^{PP,a} + (1-\lambda)\theta - 1] - 1 = \alpha q(1-\lambda)p_H - 1 + \alpha q(\theta - 1) < \mathcal{L}_F^P$ by Assumption 3 and $\alpha < 1$. In case (b), the PC of HL-sellers is more restrictive than the PC of HH-sellers. Because of Assumption 1, the feasibility constraint of HL-sellers is even more restrictive and binds, so $r^{PP,b} = p_L$. Since the share of H-sellers is q, the expected profit of the lender is $q[r^{PP,b} + (1-\lambda)\theta - 1] - 1 = qp_L - 1 + q[(1-\lambda)\theta - 1] < \mathcal{L}_F^S$ because of $q < 1$.

Proof of Proposition 1. Straightforward algebra reveals that the payoff in Eq. (6)(b) is non-negative iff

$$\lambda \leq \lambda_F^S \equiv \frac{p_L - 1 + q(\theta - 1)}{q\theta + (1-q)p_L} \qquad \text{(A.4)}$$

Similarly, (6)(c) is non-negative iff

$$\lambda \leq \lambda_F^P \equiv \frac{p_L - 1 + \alpha q(\theta - 1)}{p_L}. \qquad \text{(A.5)}$$

Combining these two conditions with Lemmas 2 and 3 yields the results in the Proposition.

Proof of Lemma 4. Since there are only two types of matches with online sales, the lender's choice under online distribution is either a separating, a fully pooling, or a partial participation contract. (Partial pooling does not apply with two matches m.)

Consider the *separating contract* first. As usual, the PC of L-sellers binds, $r_L^{\mathcal{P}} = (1-\lambda)p_L$, where the superscript indicates that trades are settled in $\mathcal{P}$-money. The ICs are

$$\begin{aligned}p_H - r_H^{\mathcal{P}} + \lambda\theta &\geq p_H - r_L^{\mathcal{P}} \\ p_L - r_L^{\mathcal{P}} &\geq p_L - r_H^{\mathcal{P}} + \lambda,\end{aligned}$$

which together with profit-maximization yield $r_H^{\mathcal{P}} = r_L^{\mathcal{P}} + \lambda\theta$. Feasibility is ensured by Assumption 1. The lender's expected profits under separation are

$$\begin{aligned}\mathcal{L}_O^S &= q\left[r_H^{\mathcal{P}} + (1-\lambda)\theta - 1\right] + (1-q)r_L^{\mathcal{P}} - 1 \\ &= (1-\lambda)p_L + q(\theta - 1) - 1.\end{aligned}$$

The *pooling contract* again yields $\bar{r} = (1-\lambda)p_L$, so expected lender profits are $(1-\lambda)p_L - 1$. This is strictly lower than under separation (the lender learns nothing under the pooling contract and, therefore, does not extend a second loan).

Finally, a *partial participation contract* sets a single repayment r^{PP}, so no ICs are required. The repayment is set for the PC of H-sellers to bind, so $r^{PP} = (1-\lambda)p_H + \lambda\theta$, which is feasible by Assumption 1. L-sellers default on the initial loan and absconds with sales, so the lender receives nothing from them but the partial participation contract allows her to extract more surplus from H-sellers. The expected lender profits is $q(1-\lambda)p_H - 1 + q(\theta - 1)$, which is lower than the expected profit under separation because of the low share of high types (Assumption 3).

Proof of Corollary 1. Note that $q < \frac{\theta - p_L}{\theta(\theta-1)}$ implies $\lambda^{\mathcal{P}} < \bar{\lambda}$, so that $\mathcal{P}$-money leads to no loan for at least some $\lambda < \bar{\lambda}$. Next, we establish that $\hat{\lambda}$ and λ_0 cross at $\lambda = 1$, and thus at the border or outside the relevant parameter space. Indeed, we have

$$\begin{aligned}\lambda_0 \equiv \alpha \frac{\Delta_p}{p_H - \theta} &= (1-\alpha)\frac{\Delta_p}{\theta - p_L} \equiv \hat{\lambda} \\ \iff \alpha &= \frac{p_H - \theta}{\Delta_p}\end{aligned}$$

so that $\lambda_0|_{\alpha = \frac{p_H - \theta}{\Delta_p}} = 1$. Hence, we have $W^D = W^{\mathcal{P}}$ for $\hat{\lambda} < \lambda < \lambda_S$.

Moreover, for $\lambda \in [\underline{\lambda}, \bar{\lambda}] \setminus [\hat{\lambda}, \lambda_S]$, we have that $W^{\mathcal{P}} = W^O \equiv qp_H + (1-q)p_L - 1 + q(\theta - 1)$ for $\lambda > \lambda^{\mathcal{P}}$ and $W^{\mathcal{P}} = 0$ otherwise. This is the best respectively worst outcome possible, so we must have $W^{\mathcal{P}} \geq W^D$ for $\lambda > \lambda^{\mathcal{P}}$ and $W^{\mathcal{P}} \leq W^D$ otherwise.

Appendix B. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jfineco.2025.104050.

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