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# "Mobile money agent interoperability and liquidity management"

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# Mobile money agent interoperability and liquidity management*

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**Abstract**

We study agents that provide Cash-In/Cash-Out (CICO) services to mobile money consumers. A moral hazard friction constrains these agents' ability to hold liquid reserves, which creates an endogenous cost for operators of ensuring reliable CICO services. Interoperability that allows agents to contract with multiple operators tends to decrease the amount of liquidity held by agents when the moral hazard problem is mild through a higher utilization rate but can increase it when the moral hazard problem is severe. In the latter case, the fees paid by operators to agents become strategic complements sustaining multiple equilibria with different levels of liquidity. Fees from operators to agents tend to be inefficiently low from a welfare perspective, both because operators internalize agents' agency rents as a cost and because they do not internalize that higher fees, by expanding agents' capacity to hold liquidity, benefit consumers from other operators. In that context, authorizing interoperability can decrease (when moral hazard is mild) or increase (when moral hazard is severe) welfare.

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Financial inclusion has made major progress in the past two decades, particularly in developing countries. In 2022, the World Bank reports that 76% of the world's adult population had a bank account and that the number of adults without access to an account has declined from 2.5 billion in 2011 to 1.7 billion in 2017 to 1.4 billion in 2021.[1] The development of mobile money -the possibility to hold a bank account via a mobile phone- has been a major driver of this trend, with over 1.35 billions registered accounts in 2021. The rapid adoption and growth of this payment solution since the early experiment by M-PESA in Kenya in 2007 has created dynamic markets in many countries where multiple mobile money services are now available for consumers. With these markets reaching maturity, new questions arise on what the next phase of development should be. In particular, the question of interoperability between mobile payment systems has been at the forefront of the agenda of regulators and industry players.[2] Interoperability generally refers to the ability for users to perform transactions across mobile payment providers, but is a multi-layered concept (Bianchi et al., 2023). In this paper we zoom in on one of these layers, namely agent interoperability. This is the possibility for mobile money agents to perform services for consumers on behalf of multiple mobile money operators.

Agent networks are key infrastructures in the functioning of mobile money networks (Aker et al., 2020).[3] For example, they are pivotal in on-boarding and educating consumers on the use of mobile money (Davidson and Leishman, 2012). One of their vital role is to provide consumers with Cash-In / Cash-Out (CICO) services. In economies where cash is present in a large share of transactions, CICO agents perform the key function of converting digital balances into cash and vice versa. This function creates two challenges that are the focus of this study. First, to service consumers, agents need to maintain a float of both digital and cash

[1] https://www.worldbank.org/en/topic/financialinclusion/overview.

[2] See, e.g., the 2020 GSMA Insight report, "Tracking the journey towards mobile money interoperability," https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2020/06/GSMA_Tracking-the-journey-towards-mobile-money-interoperability-1.pdf

[3] There were an estimated 5.6 million mobile money agents around the world in 2021, converting over $700 million per day. Source: https://www.gsma.com/mobilefordevelopment/programme/mobile-money/mobile-money-agents-sustainability-in-a-digital-era/

balances at any point in time. Evidence suggests significant frictions in that dimension. For example, a 2023 report by Innovations for Poverty Action (IPA) estimates that in Bangladesh, Tanzania and Uganda, the physical costs for consumers to access the liquidity provided by agents, including the probability that the agent may not be available or may not have enough liquidity to complete the transaction are 3 to 10 times higher than the transaction fee itself.[4] These costs are particularly significant given the small size of most transactions. The second challenge is that agents perform these tasks on behalf of mobile money providers, sometimes in very remote areas and with very little scope for oversight. This implies agents need to be properly incentivized to perform in a reliable manner. There also, evidence suggests that agency frictions lead to a deterioration of the service consumers receive from agents (see, e.g., Annan (2022)).

We encapsulate these ingredients in a model of CICO delegation. The basic building block features a mobile money operator (later referred to as "operator") who sells digital payment services to consumers. Consumers sometimes need to convert their digital balances into cash, an event we refer to as a liquidity shock. To allow conversion into cash, the operator needs to hire a CICO agent (later referred to as "agent") who fulfills consumers' withdrawal request using a liquidity float. In the model, the size of that float is constrained by a moral hazard problem. Agents borrow the liquidity they deploy but because they cannot commit not to misuse this capital, the size of the loan is a multiple of the collateral they can pledge (equivalently, of the capital they can themselves deploy). Importantly, that multiple increases with the fee agents receive from operators every time they service a consumer. A higher fee makes CICO more profitable, hence provides better incentives for the agent to use capital efficiently. This implies the operator faces an *agency* cost of providing consumers access to liquidity: through the fee paid to agents, the operator controls the float his agent holds, and therefore the reliability of CICO services.

We start by the analysis of the non-interoperable case where each operator is paired with

[4] https://poverty-action.org/publication/transaction-cost-index-year-1-comparative-report

just one agent. This benchmark case features a classical rent-efficiency trade-off. If incentives for the agent to divert funds are not too strong, the operator chooses to induce the agent to hold a large float, and fully insures consumers against liquidity shocks. CICO is then fully reliable in that consumers are always able to withdraw when needed. However, as the moral hazard problem worsens, the operator chooses to economize on the agent's rent which causes his agent to hold a smaller float. This strategy reduces the agency cost for the operator but is inefficient as some consumers with a liquidity shock are now unable to withdraw. The quality of the operator's service then deteriorates and with it, the price he can charge to consumers. In cases where the moral hazard problem is more severe, this could even prevent the operator from offering a viable product altogether. Interestingly, even in cases where the mobile money market does not break down, this non-operable case features inefficiencies. This is because the operator internalizes the rent he pays to the agent as a cost, while it is a transfer from a social planner's point of view. As a result, the social planner may want the agent to hold more liquidity than the operator does.

We next turn to the interoperable agent case which has two defining features. First, operator 1 can contract with operator 2's agent for the provision of liquidity services to operator 1's consumers. Second, an agent that contracts with multiple operators can use a common float to serve consumers from any of these operators. In other words, the liquidity the agent holds is not segregated in separate accounts each devoted to serving the consumers of one particular operator. In that sense, interoperability entails more than non-exclusivity.[5] The ability for agents to serve all consumers using the same float has a diversification benefit. To the extent that consumers' shocks are not perfectly correlated across operators, the utilization rate of agents' liquidity goes up. Put differently, the ability for consumers to use the float of another operator's agent when their own agent runs out allows the system to deliver the same level of liquidity to consumers (at least in some states) with less overall liquidity. It is then intuitive that this would lead agents to hold less liquidity in equilibrium, while improving

[5]See Rattel et al. (2024).

operators' ability to offer a viable service. There are however two caveats. First, this lower equilibrium level of liquidity need not be welfare improving relative to the non-interoperable case. This is because the agents' rents still drive a wedge between the social planner and operators. Operators have an excessive tendency to take advantage of the efficiency gains from diversification to economize on the agents' rents, and liquidity can then be inefficiently low, not only relative to what a social planner could implement with interoperability, but also relative to the equilibrium without interoperability. Second, the result that the overall liquidity in the system goes down holds only when the moral hazard problem is mild, as we discuss next.

The reason why moral hazard interacts with interoperability is because agents' ability to contract with multiple operators increases the potential revenue they derive from providing liquidity services to consumers. As a result, agents' incentives to misuse their capital goes down. This generates strategic complementarities across operators that are stronger when the moral hazard problem is more severe. When one operator increases the fees he pays to agents, the marginal cost of incentivizing agents goes down for the other operator, which can also lead him to increase agents' fees. Strategic complementarities have three consequences on equilibrium outcomes. First, they sustain equilibria with higher levels of liquidity than without interoperability despite the potential for diversifying shocks which naturally pushes towards less equilibrium liquidity, as discussed above. Second, there can be equilibrium multiplicity with equilibria with low levels of liquidity (or even no mobile money service at all) co-existing with equilibria with high levels of liquidity. The former are Pareto-dominated by the latter showing the possibility of coordination failures. Second, even the "best" equilibrium can be inefficient not just from a social planner point of view, but even from an industry point of view: operators could increase their joint profit by committing to paying higher fees to agents. Note that the issue of agents' fees being too low is often mentioned as a hurdle for the development of agents' networks.[6]

[6] https://www.gsma.com/mobilefordevelopment/programme/mobile-money/

Overall our model suggests that interoperability might be particularly valuable when the moral hazard friction at the agent's level is more severe. Despite the potential for miscoordination, interoperability improves welfare relative to the non-operable case by allowing both higher levels of liquidity (even in the worst equilibrium), a more efficient use of liquidity (the diversification effect) and down the line a higher probability of making the mobile money service viable for the operator.

The literature that is thematically the closest to our object of interest looks at interoperability of ATM networks. Indeed, functionally, ATMs deliver the same cash-out service as CICO agents for mobile money. This literature has mostly focused on the impact of ATM interoperability on competition between banks and on the pricing of cash-out services. A review of this stream of papers with connections to CICO agents is in Bianchi et al. (2023), in section 5.1. Relative to this literature, our main point of differentiation is our focus on agents' moral hazard, an issue that is obviously irrelevant in the case of ATMs, and more specifically on how this moral hazard friction is affected by interoperability.

# 1 The model

## 1.1 Description

We consider a model with three dates, $t = 0, 1, 2$, where everyone is risk-neutral and the risk-free rate is normalized to 0. There are mobile money operators indexed by $\theta \in \{1, 2\}$. Each operator serves a continuum of captive homogenous consumers of mass 1, who each owns 1 dollar. At $t = 1$, consumers of operator $\theta$ can deposit their dollar in the mobile wallet operated by their operator and enjoy a benefit $b > 0$ from using electronic payment services. This benefit captures the security and convenience of storing value electronically and of using it in digital transactions. However, at $t = 2$, consumers who deposited at $t = 1$ may need to convert their electronic balance back into cash. If they cannot do so, they suffer a disutility

mobile-money-agents-sustainability-in-a-digital-era/

equal to $c > 0$. To capture the potential for diversifying consumers' withdrawal needs across operators, we adopt a simple probability structure. With probability $\alpha$ withdrawal needs are perfectly correlated: consumers from both operators want to withdraw. With probability $1-\alpha$, either consumers of operator 1 or consumers of operator 2 want to withdraw, each configuration happening with equal probability 0.5.

To allow consumers to withdraw, operators need to contract with Cash-In/Cash-Out (CICO) agents. The role of CICO agents is to accept cash and credit the corresponding amount in the consumer's digital account (cash-in), or to provide cash and debit the consumer's digital account (cash-out). To provide these cash services, agents need to hold a reserve of cash (a float) as well as a digital account with the mobile money operator they represent. For expositional ease, we describe here the case where agents are not interoperable and will explain in Section 3 how interoperability affects both contracting between operators and agents and CICO services for consumers. Absent interoperability, each operator $\theta$ contracts with one agent $\theta$ who can only serve the consumers of that operator. To do so, agent $\theta$ holds a float $L_\theta$ from which consumers withdraw. We assume sequential service, that is, consumers who want to withdraw are randomly placed in a line and served as long as the agent has some liquidity left. Given our assumptions on consumers' withdrawal needs, this implies in particular that if $L_\theta < 1$, some consumers will not be able to withdraw when facing a cash need and therefore will incur the disutility $c$. A $t = 0$, the operator offers a contract to its agent.

Last, CICO agents are subject to a moral hazard problem. They hold an asset $A$ that can be pledged in a financial contract, and need to borrow $L_\theta$ in a competitive credit market to perform withdrawals services. We assume each agent can abscond with the amount of the loan, in which case she gives up the revenues from performing CICO services but enjoys a benefit $\phi L_\theta$, with $\phi < 1$.

The timing of the model is as follows. At $t = 0$, mobile money operators set the consumer price $P_\theta$ for access to their mobile money service, and the fee $f_\theta$ they pay to their agent any time they serve a consumer. At $t = 1$, CICO agents contract with a lender and consumers decide whether to buy access from their operator. Finally, at $t = 2$, consumers who want to withdraw attempt to do so, CICO agents serve consumers as long as they hold funds, and the operator credits the agent's account by the amount paid out to consumers augmented with a fee $f_\theta$ per consumer.

## 1.2 Discussion

We briefly discuss here our modeling choices and their implications. The first remark is that we abstract from costs both on the side of the operator and on the side of the agent. Our approach is without much loss of generality. For example, if the operator incurs a cost per consumer, then we can simply reinterpret the consumer surplus $b$ as being net of that cost. Similarly, if the agent faces a cost every time he serves a consumer -this could for example be the opportunity cost of not using cash for another activity- then the fee $f_\theta$ becomes the payment to the agent net of that cost. In other words, our assumptions are normalizations that focus the attention on the endogenous cost for the operator generated by the agency problem.

On that agency friction, the specific setup we adopt is only one way to capture the effect that increasing the liquidity float comes with an agency cost for the operator. A hidden-effort problem could create the exact same economic effect. For example, in the spirit of Holmström and Tirole (1997), we could assume that if the agent exerts unobservable effort, then he can serve all consumers, while if he does not, he serves consumers with probability $p < 1$ but enjoys a private benefit $B$. That specification generates the same analytical expressions as the specification described above.

A more substantial omission from our setup is competition between operators. We shut this channel down for two reasons. First, it helps keep the model tractable and second, it isolates the effects that are purely driven by the financial constraint of the agent. Competitive effects have been a major focus of the literature on interoperability (see Bianchi et al. (2023)), and we wish to look at this question from a different angle. That said, there could be interesting interactions between the competitive effects of interoperability and the agency friction we introduce in this model.

## 2 Cash-in/Cash-out without agent interoperability

Consider first the financial contracting problem of the CICO agent. Given that consumers are homogenous, the operator will either sell to all consumers or to none. Therefore if the agent contracts with the operator, he will face a mass one of consumers if these consumers need to withdraw, which happens with probability $\alpha + \frac{1-\alpha}{2}$. So if the agent deploys capital $L_\theta$ and does not abscond with the borrowed money, her payoff (gross of financing cost) is

$$\left(\alpha + \frac{1-\alpha}{2}\right) f_\theta L_\theta.$$

If she does run with the capital, she gets the benefit $\phi L_\theta$ but loses her collateral $A$. Since the credit market is competitive, lenders lend at a zero interest rate as long as they always recover their capital, which is the case if the agent does not run. Therefore the agent's incentive compatibility constraint is

$$\left(\alpha + \frac{1-\alpha}{2}\right) f_\theta L_\theta \geq \phi L_\theta - A. \tag{1}$$

If $A \geq \phi$, then the agent is not financially constrained in that she can deploy $L_\theta = 1$ that allows her to always serve consumers without the incentive provided by the operator's fee $f_\theta$. To focus on the more interesting case where the agent is financially constrained we assume

**Assumption 1**

$$\phi > A.$$

Then the operator optimally sets the fee $f_\theta$ such that (1) is binding, which implies $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) f_\theta$ and

$$L_\theta = \frac{A}{\phi - \left(\alpha + \frac{1-\alpha}{2}\right) f_\theta}. \tag{2}$$

From eq. 2, $L_\theta$ is an increasing function of $f_\theta$: operators face an agency cost of ensuring more reliable cash services to their consumers. Note also that if eq. 2 holds for $L_\theta$, then it also holds for any $L < L_\theta$, that is, there is no incentive for the agent to do a "partial" run where she starts serving consumers, then stops and runs with her remaining cash. Note finally that even if $f_\theta = 0$, the agent holds $\frac{A}{\phi}$, which is strictly smaller than 1 from Assumption 1. Even if the operator does not remunerate the agent, the latter is able to borrow money to hold some minimal float by pledging her collateral $A$.

Turn now to the operator's optimal strategy, which consists of a price $P_\theta$ for mobile money consumers and a fee $f_\theta$ for the agent. The consumer pricing side is simplified by the assumption that the operator is a local monopoly and consumers are homogeneous. This implies the operator can extract the full surplus from consumers, equal to

$$b - \left(\alpha + \frac{1-\alpha}{2}\right)(1 - L_\theta)c. \tag{3}$$

Consumers derive a benefit $b$ from using the mobile money service, then face a withdrawal need with probability $\alpha + \frac{1-\alpha}{2}$ in which case they cannot be served by the agent with probability $1 - L_\theta$ and incur the disutility $c$. Then the operator's profit is

$$b - \left(\alpha + \frac{1-\alpha}{2}\right)(1 - L_\theta)c - \left(\alpha + \frac{1-\alpha}{2}\right) f_\theta L_\theta, \tag{4}$$

where $L_\theta$ is given by eq. 2 hence a function of $f_\theta$. Maximizing (4) with respect to $f_\theta$ and assuming that if the operator is indifferent between different levels of $f_\theta$, it chooses the one that results in the highest liquidity $L_\theta$, delivers the optimal (induced) level of agent's cash holding. Note that we also need to verify that the operator's profit is positive, which, as we show next depends on the agent's collateral $A$. More precisely, define

$$\overline{A} \equiv \min\left\{\phi - b, \phi - \frac{\phi}{\left(\alpha + \frac{1-\alpha}{2}\right)c} b\right\}. \tag{5}$$

**Proposition 1** *Suppose $A \geq \overline{A}$, then mobile money operators function and*

*(i) if $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right)c$, operators set $f_\theta = \frac{\phi - A}{\left(\alpha + \frac{1-\alpha}{2}\right)}$ and agents hold liquidity $L_\theta = 1$,*

*(ii) if $\phi > \left(\alpha + \frac{1-\alpha}{2}\right)c$, then $f_\theta = 0$ and $L_\theta = \frac{A}{\phi}$.*

*If $A < \overline{A}$, mobile money operators do not function.*

The conditions in Proposition 1 delineate both the incentives and the capacity for the operators to induce agents to hold liquidity. On the incentive side, the operator weighs the marginal agency cost of inducing the agent to hold liquidity, $\phi$, against the marginal (expected) benefit each consumer derives from being able to withdraw, $\left(\alpha + \frac{1-\alpha}{2}\right)c$. When the latter is larger, the operator has an incentive to increase $f_\theta$ and induce larger cash holdings $L_\theta$, to maximize his profit. Note that the condition $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right)c$ hinges on marginal costs, hence is independent from the agent's collateral $A$. However, on the capacity side, the operator needs to turn a positive profit given the total agency cost of inducing the agent to hold more cash. That total cost increases when the agent's collateral decreases, making the overall service economically non-viable for the operator when $A < \overline{A}$. Since the agent's agency rent is the only cost for the operator, this full market breakdown can be directly traced to the agency friction.

We close this section with a few remarks. The first one relates to welfare and to what a benevolent social planner facing the same agency friction would want to implement. See first that without any agency friction, welfare would be maximized by setting $L_\theta = 1$. Since holding liquidity is costless, maximizing welfare is then equivalent to maximizing consumer surplus. Note that our setup where operators fully capture consumers' surplus makes it more likely that their decisions align with overall surplus' maximization. Nevertheless, with agency frictions, the equilibrium level of liquidity is not socially optimal when the agency cost is high, i.e. when $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$. This is because the fee $f_\theta$ paid to the agent, that operators see as a cost, is an agency rent. From the planner's point of view, it is a pure transfer from operators to agents, and not a social loss. In that sense, a social planner might want to increase $f_\theta$ such that $L_\theta = 1$ even if it decreases operators' profit. We therefore define a constrained optimum as the maximal total surplus that can be reached under the constraint that the agent does not abscond with the money, and that operators are willing to offer mobile payment services. Since the agency rent is the operators' only cost and is inherently non-transferable, this definition of a constrained optimum coincides with what a social planner would directly implement under the constraint of balancing its budget. This leads to the following results.

**Corollary 1** *Assume $A \geq \overline{A}$. If $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$, then agents' cash holdings $L_\theta$ are strictly higher in the constrained optimum than in equilibrium. Otherwise, the constrained optimum's and equilibrium's cash holdings coincide.*

When $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$, the marginal cost of inducing a higher level of liquidity is larger than the marginal benefit each operator can obtain from raising the price paid by consumers. Hence without any intervention, operators induce the lowest possible level of liquidity from their agent. Social surplus is then low because consumers cannot convert their digital money into cash whenever they need to. In principle, there are several ways to implement the constrained optimum. One possibility would be to regulate fees paid to agents, and set them at a level that induces $L_\theta = 1$. Another way is to set a system of taxes (to operators) and subsidies (to agents) that induces agents to maintain a float $L_\theta = 1$ (we formally make this point in Corollary 6 in the Appendix). In either case, determining what the proper level of the fee/tax should be might prove challenging: it depends, among other things, on the magnitude of the agent's moral hazard problem which is presumably hard to estimate and heterogeneous across agents and agents' networks. As we will see next, interoperability could emerge as a more flexible way to solve this problem.

A final remark on our contracting assumptions. First, there could be other forms of contracts between the operator and the agent, but to the extent that the agent always has the ability to abscond and get a payoff $\phi L_\theta - A$, that amount is the minimum rent she needs to be left with, whatever the form of the contract. Second, we assume each agent contracts separately with a lender and with an operator. This feature is motivated by practice but is also inessential in the model. Since the credit market is competitive, funding has no cost and could equivalently be provided by the operator. In that case, other forms of optimal contracts could emerge where the operator internalizes the rent of the agent through other channels than the fee $f_\theta$ (say, through a loan contract), but the key feature would remain that this rent needs to be paid. Finally, we assume that consumers pay their expected utility from using the service ex-ante (at $t = 1$). The operator could equivalently use a two-part tariff where the consumer pays a lower access fee but is charged for withdrawals, as is the case in practice in most mobile money schemes.

# 3 Agents' Interoperability

In this section, we introduce two modifications to the model presented in Section 1 in order to capture agent's interoperability. The first modification is that we allow consumers to withdraw from both agents. Specifically, we assume that withdrawals at $t = 2$ take place in two stages. First, consumers of operator $\theta$ who wish to withdraw go to agent $\theta$. In a second stage, those who could not withdraw from agent $\theta$ can visit the other agent, denoted $-\theta$ and request a withdrawal. This specification captures that while consumers can potentially withdraw from both agents, they have a higher proximity with their own agent.

The second modification is that since consumers $\theta$ can withdraw cash from both agents, each principal can now remunerate both agents. Therefore, principal $\theta$ sets a fee $f_\theta$ when agent $\theta$ serves a consumer $\theta$ and a fee $\hat{f}_\theta$ when agent $-\theta$ serves a consumer $\theta$. When contracting with agents, each operator considers that each agent's float can be used for both consumers, which is the standard way to characterize agents' interoperability. One could also imagine a situation in which each agent can serve the consumers of both operators while managing a separate, specific float for each operator. In that case we would have agents' non exclusivity but not agents' interoperability. The fact that agents share a single float for both operators is what distinguishes interoperability from non exclusivity.[7] In the rest of the analysis, we denote $L_\theta$ the float held by agent $\theta$ (i.e., the agent favoured by consumers $\theta$), even if consumers $-\theta$ can withdraw from $L_\theta$.

Finally, to circumscribe the number of equilibrium configurations to the most relevant ones, we restrict attention to the case where the agent is more constrained.

**Assumption 2**

$$A < \min\left\{\frac{\alpha c}{2}, \frac{(1-\alpha)c}{4}\right\}.$$

## 3.1 Complementarities

To build intuition on the interactions between operators and agents under interoperability, consider first a candidate equilibrium with high liquidity, $L_1 + L_2 > 1$. In such an equilibrium demand for withdrawal is fully fulfilled when the shock to consumers is idiosyncratic.

The agent's revenue is

$$\left(\alpha + \frac{1-\alpha}{2}\right) L_\theta f_\theta + \frac{1-\alpha}{2}(1 - L_{-\theta})\hat{f}_{-\theta}.$$

With probability $\alpha + \frac{1-\alpha}{2}$, consumers of type $\theta$ are shocked and then fully use the liquidity of agent $\theta$. With probability $\frac{1-\alpha}{2}$, consumers of type $\theta$ are not shocked but consumers of type $-\theta$ are. In that case, a mass $1 - L_{-\theta}$ of consumers of type $-\theta$ who could not withdraw from their agent withdraw from agent $\theta$.

Considering now that agent $\theta$ obtains another source of revenue from operator $-\theta$, the amount of funds that the agent can raise must satisfy the following incentive compatibility

[7] This distinction is made notably by GSMA (see Rattel et al. (2024))

constraint

$$\left(\alpha + \frac{1-\alpha}{2}\right) L_\theta f_\theta + \frac{1-\alpha}{2}(1 - L_{-\theta})\hat{f}_{-\theta} \geq \phi L_\theta - A. \tag{6}$$

Since operators optimally set their fees such that eq. 6 is binding, and since $L_\theta \leq 1$, we must have $\phi - \left(\alpha + \frac{1-\alpha}{2}\right) f_1 > 0$ in equilibrium, and the agent's incentive compatible float is defined by

$$L_\theta = \frac{A + \frac{1-\alpha}{2}(1 - L_{-\theta})\hat{f}_{-\theta}}{\phi - \left(\alpha + \frac{1-\alpha}{2}\right) f_\theta}. \tag{7}$$

A comparison between eq. 2 and eq. 7 illustrates the interaction between the fees set by the operators. First, the ancillary revenue agent $\theta$ gets from serving consumers $-\theta$ has the same effect as increasing her collateral $A$: it increases the (opportunity) cost of absconding with $L_\theta$, which relaxes the agency problem, i.e., $L_\theta$ increases in $\hat{f}_{-\theta}$. This implies that a strictly positive $\hat{f}_{-\theta}$ makes it cheaper for operator $\theta$ to incentivize his own agent to hold liquidity, i.e.,

$$\frac{\partial^2 L_\theta}{\partial f_\theta \partial \hat{f}_{-\theta}} > 0. \tag{8}$$

On the other hand, an increase in the other agent's float $L_{-\theta}$ reduces the magnitude of that externality. In other words, when operator $-\theta$ increases the fee to his own agent $f_{-\theta}$, thereby increasing $L_{-\theta}$, he limits the ability of agent $\theta$ to capture the ancillary revenue associated with $\hat{f}_\theta$. So, if $\hat{f}_{-\theta} > 0$, then

$$\frac{\partial^2 L_\theta}{\partial f_\theta \partial f_{-\theta}} < 0. \tag{9}$$

It follows that in an equilibrium with high liquidity, fees exhibit a combination of complementarities (between $f_\theta$ and $\hat{f}_{-\theta}$) and substitutabilities (between $f_\theta$ and $f_{-\theta}$) across the two operators.

Turn to the candidate equilibrium with low liquidity, $L_1 + L_2 \leq 1$. Agent $\theta$'s incentive compatibility constraint is

$$\left(\alpha + \frac{1-\alpha}{2}\right) L_\theta f_\theta + \frac{1-\alpha}{2} L_\theta \hat{f}_{-\theta} \geq \phi L_\theta - A,$$

which implies (given that the constraint is binding in equilibrium)

$$L_\theta = \frac{A}{\phi - \left(\alpha + \frac{1-\alpha}{2}\right) f_\theta - \frac{1-\alpha}{2} \hat{f}_{-\theta}}. \tag{10}$$

Note that in contrast to the case where liquidity is more abundant (eq. 7), $L_\theta$ does not depend on the liquidity of the other operator, $L_{-\theta}$. This is because when liquidity is scarce, $L_\theta$ is fully used by consumers of operator $-\theta$ when they have an idiosyncratic shock. This removes the source of substitutability in eq. 9, so that only the complementarity,

$$\frac{\partial^2 L_\theta}{\partial f_\theta \partial \hat{f}_{-\theta}} > 0$$

remains. We will see in the analysis of the case where agents' moral hazard problem is more severe that these complementarities play an important role in generating equilibrium multiplicity and coordination failures.

## 3.2 Moderate moral hazard: $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right) c$.

We start with the case where the moral hazard problem is milder, i.e., $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right) c$. Recall that in this case, agents hold $L_\theta = 1$ when interoperability is not possible. A natural question is then whether this equilibrium still exists. For $L_1 + L_2 > 1$, the utility consumers derive from using the mobile money service is

$$b - \alpha(1 - L_\theta)c. \tag{11}$$

Note that in general, this is higher than their utility without interoperability (3) as consumers only incur the cost $c$ of not being able to withdraw when the shock is systematic (probability $\alpha$). Since operators can set the price of their digital payment services to capture all their consumers' surplus, each operator's profit is now written

$$b - \alpha(1 - L_\theta)c - \left(\alpha + \frac{1-\alpha}{2}\right) L_\theta f_\theta - \frac{1-\alpha}{2}(1 - L_\theta)\hat{f}_\theta. \tag{12}$$

Note that operator $\theta$'s profit is decreasing in $\hat{f}_\theta$ for two reasons. First, as is apparent from eq. 12, increasing $\hat{f}_\theta$ increases the amount operator $\theta$ pays to agent $-\theta$ without a corresponding marginal liquidity benefit for his consumers: they use the liquidity of agent $-\theta$ when their shock is idiosyncratic in which case there is already enough liquidity ($L_1 + L_2 > 1$) to serve all of them. There is also an indirect effect: $\hat{f}_\theta$ affects $L_{-\theta}$ which, from eq. 7, enters the expression for $L_\theta$. But that effect is also negative: when operator $\theta$ pays agent $-\theta$ more, inducing her to hold more liquidity $L_{-\theta}$, agent $\theta$ has fewer opportunities to serve the consumers of operator $-\theta$, which tightens her financial constraint and weakens the marginal efficiency of the direct fee $f_\theta$ on $L_\theta$.

It follows that in an equilibrium such that $L_1 + L_2 > 1$, $\hat{f}_\theta = 0$. This should be interpreted as operator $\theta$ not paying any rent to agent $-\theta$, i.e., not compensating her for anything more than her marginal cost of serving consumers $\theta$ (here normalized to zero). Finally, optimizing eq. 12 with respect to $f_\theta$, we get the following intermediate result.

**Lemma 1** *There exists an equilibrium such that $L_1 = L_2 = 1$ if and only if $\phi \leq \alpha c$ and $A \geq \overline{A}$.*

Two remarks on this intermediate result. First Lemma 1 implies there is less liquidity in the system under interoperability: the condition $\phi \leq \alpha c$ in Lemma 1 under which liquidity is maximal (i.e. $L_1 = L_2 = 1$) is tighter than without interoperability (Proposition 1). This is because interoperability allows operators to diversify their consumers' shocks across agents. Comparing profits with and without interoperability (eq. 4 versus eq. 12), the marginal benefit of liquidity goes down from $\left(\alpha + \frac{1-\alpha}{2}\right) c$ under no interoperability to only $\alpha c$ with interoperability: with interoperability, liquidity $L_\theta$ is useful at the margin to better cover the (expected) systematic shock $\alpha c$, but not the idiosyncratic one $\left(\frac{1-\alpha}{2}\right) c$ which is covered by the other operator. This makes it more difficult to sustain an equilibrium with full liquidity coverage. Second, the condition $A \geq \overline{A}$ under which operators can turn a positive profit is the same in Lemma 1 as with no interoperability (Proposition 1). Recall that this condition is related to the total rent that needs to be left to the agent to allow her to deploy $L_\theta$. Here, even though diversification affects the conditions under which full liquidity coverage is an equilibrium, as we just discussed, in an equilibrium where $L_1 = L_2 = 1$, there is no diversification: each agent has always enough to serve her own consumers. It follows that in this equilibrium, interoperability does not relax the funding constraint of agents.

We investigate next the existence of an equilibrium with $L_1 + L_2 \leq 1$. In that case, consumers' utility is

$$b - \left(\alpha(1 - L_\theta) + \frac{1-\alpha}{2}(1 - L_\theta - L_{-\theta})\right) c,$$

and each firm's profit is

$$b - \left(\alpha(1 - L_\theta) + \frac{1-\alpha}{2}(1 - L_\theta - L_{-\theta})\right) c - \left(\alpha + \frac{1-\alpha}{2}\right) L_\theta f_\theta - \frac{1-\alpha}{2} L_{-\theta} \hat{f}_\theta. \qquad (13)$$

Note that unlike in equilibria where liquidity is abundant ($L_1 + L_2 > 1$), there is now a potential benefit for operator $\theta$ to increase $\hat{f}_\theta$: it stimulates liquidity holding by agent $-\theta$ which, at the margin, reduces the impact of an idiosyncratic shock for his own consumer by an expected $\frac{1-\alpha}{2} c$. In addition, from eq. 10, $L_{-\theta}$ no longer enters the expression for $L_\theta$ (unlike in eq. 7), that is, there is no business stealing effect when $L_{-\theta}$ increases on agent $\theta$. This is because consumers of operator $-\theta$ fully use the liquidity $L_\theta$ of agent $\theta$ when suffering an idiosyncratic shock. This suppresses one cost for operator $\theta$ to stimulate $L_{-\theta}$ through $\hat{f}_\theta$. Taken together, these observations suggest there could exist an equilibrium where both $f_\theta$ and $\hat{f}_\theta$ are strictly positive.

Let

$$\underline{A} \equiv \frac{\phi}{2} - b + \frac{\alpha}{2}c.$$

**Lemma 2** *If $\alpha c < \phi \leq \left(\alpha + \frac{1-\alpha}{2}\right)c$ and $A \geq \underline{A}$, there exists an equilibrium such that $L_1 = L_2 = \frac{1}{2}$.*

The equilibrium in Lemma 2 confirms the intuition that as the agency cost $\phi$ increases, operators are more likely to take advantage of diversification to cut liquidity. Note however that in this intermediate region, the agency cost is not so high that operators go all the way to setting fees to zero. In fact, the equilibrium in Lemma 2 is in general sustained by strictly positive $f_\theta$ and $\hat{f}_\theta$, that is, operators provide incentives to both their own agent and the agent of the other operator. A second note is that in this region, an equilibrium with strictly positive liquidity is more likely to exist than without interoperability (Proposition 1): $\underline{A} < \overline{A}$. Because consumers now have the option to use the other agent's liquidity, the impact on demand when agents own less liquidity is lower. This allows operators to economize on agents' agency rent without deteriorating consumers' willingness to pay too much. This, in turn makes it more likely that operators' businesses are viable.

Lemma 1 and Lemma 2 provide the basis for the next proposition that characterizes equilibria in this region with moderate moral hazard. In addition to these two intermediate results, this proposition states that the equilibria discussed above are the only ones.

**Proposition 2** *Suppose $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right)c$.*

*(i) If $\phi \leq \alpha c$ and $A \geq \overline{A}$, then $L_1 = L_2 = 1$,*

*(ii) if $\phi > \alpha c$ and $A \geq \underline{A}$, then $L_1 = L_2 = \frac{1}{2}$,*

*(iii) otherwise, operators are not active.*

Contrasting Proposition 2 with Proposition 1 allows a first evaluation of the effects of interoperability when agency problems are not too severe. On the positive side, this analysis predicts that interoperability reduces overall liquidity in the agent network (conditional on operating). While this may seem a natural consequence of the potential for diversifying consumers' liquidity shocks, we will see in the next section where agency problems are more severe that this need not always be the case. In addition, the analysis predicts that operators are more often able to function. While we take the number of firms as given in this model, this observation is at minimum consistent with the notion that interoperability favors entry.

On the normative side, the analysis is contrasted. On the one hand, the result that interoperability relaxes the conditions under which operators are active is unambiguously positive. However, conditional on operators being active without interoperability ($A \geq \overline{A}$), instances where liquidity is lower with interoperability are bad for welfare. This, again, is because payments to agents are transfers, hence irrelevant to a welfare analysis and therefore higher liquidity always raises welfare. Precisely, when $\phi > \alpha c$, operators are better off with interoperability, agents are worse off and overall welfare is lower. Note that this discussion also suggests that equilibrium outcomes under interoperability may not be constrained optimal.

**Corollary 2** *Suppose* $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right) c$.

*(i) When* $\phi > \alpha c$ *and* $A > \overline{A}$*, interoperability reduces welfare, and equilibrium liquidity is lower than in the constrained optimum.*

*(ii) When* $\phi > \alpha c$ *and* $\underline{A} < A < \overline{A}$*, interoperability improves welfare, but equilibrium liquidity is lower than in the constrained optimum.*

*(iii) Otherwise, interoperability is neutral for welfare and the equilibrium is constrained optimal.*

A last question in this section is whether operators jointly maximize the profit of the industry. As mentioned in Section 3.1, complementarities between operators' fees suggest they may not completely internalize how their decisions affect each other. In the case where moral hazard is moderate, the equilibrium outcome remains optimal despite these externalities.

**Corollary 3** *Suppose* $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right) c$*. Then the equilibrium outcome maximizes the mobile money industry profit.*

### 3.3 Severe moral hazard: $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$

Recall that when $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$, agents hold the minimal level of liquidity $L_\theta = \frac{A}{\phi}$ absent interoperability if they can operate at all. With interoperability, the equilibrium level of liquidity also goes down as the agency cost $\phi$ increases. More interestingly, increasing the severity of the moral hazard problem allows the complementarities discussed in Section 3.1 to surface. Indeed, these complementarities between operators' fees are driven by the agents' incentive problems.

To get a sense of the effect of these complementarities, consider the operator's profit in the case where liquidity is scarce, $L_1 + L_2 \leq 1$, which corresponds to eq. 13. The derivative of this profit with respect to $f_\theta$ has the sign of

$$\left(\alpha + \frac{1-\alpha}{2}\right) c - \phi + \frac{1-\alpha}{2} \hat{f}_{-\theta}. \tag{14}$$

The first two terms in eq. 14 capture the marginal benefit of increasing $f_\theta$ for operator $\theta$ with no interoperability: it compares the agency cost $\phi$ (per unit of liquidity) to the consumer benefit $\left(\alpha + \frac{1-\alpha}{2}\right) c$. Interoperability is captured by the third term which reflects one externality from operator $-\theta$ to operator $\theta$: as discussed in Section 3.1, the marginal cost for operator $\theta$ to induce more liquidity holding by his agent goes down when the fee $\hat{f}_{-\theta}$ from operator $-\theta$ to that same agent $\theta$ increases.

Conversely, the derivative of the operator's profit with respect to $\hat{f}_\theta$ has the sign of

$$\frac{1-\alpha}{2} c - \phi + \left(\alpha + \frac{1-\alpha}{2}\right) f_{-\theta}, \tag{15}$$

which shows a similar pattern: a higher $f_{-\theta}$ induces a higher $\hat{f}_\theta$. When the other operator induces more liquidity by increasing his own agent's fee, operator $\theta$ is encouraged to also raise the fee to agent $-\theta$ so that consumers $\theta$ benefit from a larger float when their shock is idiosyncratic.

These linkages create a chain of complementarities. Imagine that operator 1 anticipates that operator 2 will set $\hat{f}_2 = 0$. Then from eq. 14, given that $\phi > \left(\alpha + \frac{1-\alpha}{2}\right)c$, his best response is to set $f_1 = 0$. Then from eq. 15, operator 2's best response to $f_1 = 0$ is indeed to set $\hat{f}_2 = 0$. This implies that in this region where moral hazard is more severe there always exists an equilibrium with either the minimal level of liquidity, $L_\theta = \frac{A}{\phi}$, or no operation as in the non-interoperable case (Proposition 1). However, these same strategic complementarities could sustain equilibria with a higher level of liquidity where higher fees from one operator make it profitable for the other operator to increase his own fees. We formalize this in the next lemma. Let

$$\hat{A} \equiv \phi\left(\alpha + \frac{1-\alpha}{2} - \frac{b}{c}\right),$$

and note that for $\phi > \left(\alpha + \frac{1-\alpha}{2}\right)c$, we have $\underline{A} < \hat{A} < \overline{A}$.

**Lemma 3** *Assume* $\left(\alpha + \frac{1-\alpha}{2}\right)c < \phi < c - 2A$. *If* $A > \underline{A}$, *there exist multiple equilibria.*

*(i) There is one equilibrium such that fees are strictly positive and* $L_1 = L_2 = \frac{1}{2}$.

*(ii) There is one equilibrium such that if* $A > \hat{A}$, *all fees are set to 0 and liquidity is minimal,* $L_1 = L_2 = \frac{A}{\phi}$, *and if* $A < \hat{A}$ *there is no active operator.*

*If* $A < \underline{A}$, *there is no active operator.*

Lemma 3 highlights two effects of interoperability. The first one is that, unlike in the case where moral hazard is mild (Section 3.2), there can be more liquidity with interoperability than without. This happens despite the fact that interoperability, by allowing operators to diversify their consumers' shocks across agents, reduces the impact of holding lower liquidity on demand. But interoperability also has an incentive benefit: because agents now care about the revenue they can obtain from the other operator, they are less willing to abscond with $L_\theta$, hence they are cheaper to incentivize under interoperability. When moral hazard is severe, that effect dominates the diversification effect and interoperability increases both liquidity and welfare.

The second effect is that interoperability creates a coordination problem driven by the strategic complementarities discussed above. In particular, if

$$\underline{A} < A < \hat{A}$$

a "good" active equilibrium with $L_1 = L_2 = \frac{1}{2}$ coexists with a complete market breakdown with no active operators. Obviously, welfare is higher in the active equilibrium, but the market breakdown equilibrium is a coordination failure in the sense that operators are also better off in the active equilibrium.[8]

A more extreme form of coordination failure arises when $\phi$ becomes larger, as equilibria with strictly positive fees disappear.

**Lemma 4** *Suppose $\phi > c - 2A$. Then if $A \geq \hat{A}$, liquidity is minimal, $L_1 = L_2 = \frac{A}{\phi}$. Otherwise, there is no active operator.*

When the agency cost is extreme, the cost of incentivizing the agent becomes too high to sustain positive fees in equilibrium. However, in that case, we can show that if operators could commit to fees that incentivize $L_1 = L_2 = \frac{1}{2}$, they would be better off. In other words, the contractual externality that runs through agents prevents operators not only to maximize welfare, but also to maximize their own joint profit. We summarize this discussion in the next proposition and in the corollary that follows.

**Proposition 3** *Suppose $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$.*

[8]Note that there can also exist an equilibrium such that $\frac{A}{\phi} < L_1 = L_2 < \frac{1}{2}$. That equilibrium is however unstable in that a small deviation by one operator would lead operators to either of the two equilibria described in Lemma 3. It is also Pareto-dominated by the equilibrium with $L_1 = L_2 = \frac{1}{2}$.

1. *If $\phi \leq c - 2A$, multiple equilibria exist. In the dominant equilibrium, $L_1 = L_2 = \frac{1}{2}$ if $A \geq \underline{A}$ and there is no active operator if $A < \underline{A}$.*

2. *If $\phi > c - 2A$, then $L_1 = L_2 = \frac{A}{\phi}$ if $A \geq \hat{A}$ and there is no active operator if $A < \hat{A}$.*

**Corollary 4** *Suppose $\phi > c - 2A$. Then the equilibrium outcome does not maximize the mobile money industry profit.*

Note that beyond the discussion on the potential for a coordination failure, interoperability always improves welfare in this region. First, even if we select the worse equilibrium, $L_1 = L_2 = \frac{A}{\phi}$, liquidity is as in the non-interoperable case but welfare is higher because consumers can use the liquidity of the other agent when their shock is idiosyncratic. Then because consumers' utility from using the service is higher, the condition under which the service is viable is also relaxed: $\hat{A} < \overline{A}$ (see Proposition 1). These elements are summarized in the next corollary.

**Corollary 5** *Suppose $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$.*

*(i) When $\phi \leq c - 2A$ and $A \geq \underline{A}$, interoperability increases liquidity and welfare,*

*(ii) When $\phi > c - 2A$ and $A \geq \hat{A}$, interoperability increases welfare, and also increases liquidity when $\hat{A} \leq A < \overline{A}$,*

*(iii) Whenever operators are active ($A \geq \underline{A}$), equilibrium liquidity is lower than in the constrained optimum.*

# 4 Conclusion

We analyze how interoperability of agents who provide CICO services affects the reliability of these services for mobile money users. We consider a model in which mobile money users sometimes need to convert their digital money into cash, an operation that is only possible if the agent who works for their mobile money operator holds enough float. When agents have little personal wealth, operators need to pay them fees to overcome agency frictions and incentivize agents to hold enough liquidity.

In that context, interoperability affects overall liquidity in several ways. First, it allows operators to offer better cash conversion services by allowing consumers to convert cash from other operators' agents, thereby reducing the need for each agent to hold a large float, and the need for operators to pay fees. This lower liquidity is sometimes beneficial for consumers, as it increases the viability of CICO services, but it can also be detrimental to consumers (compared to the non operable case) if operators are induced to economize too much on agents' fees. In that case, social surplus is larger without interoperable services.

Second, interoperability can enhance the provision of liquidity when the moral hazard problem is particularly acute. In that case, when agents are not interoperable, operators find it too costly to incentivize agents to hold more liquidity. But when agents receives fees from other operators, they are less willing to divert cash, which decreases operators' marginal cost of inducing their agent to provide liquidity. Operators' fees are then complement, which allows to sustain higher, welfare-enhancing, levels of liquidity.

Third, these complementarities lead to the existence of multiple equilibria, with high or low liquidity, as the fees chosen by one operator depend on the other operator's strategy. The inability of operators to coordinate on high fees is detrimental to welfare, and also to the profitability of the mobile money industry.

# Appendix

### Proof of Proposition 1

Rewrite each operator's profit (4) as

$$b - \left(\alpha + \frac{1-\alpha}{2}\right) c + \left(\alpha + \frac{1-\alpha}{2}\right) L_\theta(c - f_\theta). \tag{16}$$

From (16), the optimal $f_\theta$ maximizes $L(c - f_\theta)$ subject to the agent's incentive compatibility constraint (2) and to $L \leq 1$, or

$$\begin{aligned} \max_{f_\theta} \quad & A\tfrac{c-f_\theta}{\phi-\left(\alpha+\frac{1-\alpha}{2}\right)f_\theta} \\ \text{st.} \quad & f_\theta \geq 0 \\ \text{and} \quad & 1 - L_\theta \geq 0. \end{aligned} \tag{17}$$

The FOC of the Lagrangian associated to (17) is written

$$\begin{aligned} & A(-\phi + \left(\alpha + \tfrac{1-\alpha}{2}\right) f + \left(\alpha + \tfrac{1-\alpha}{2}\right)(c - f)) + \lambda_f - \lambda_L \tfrac{\partial L_\theta}{\partial f_\theta} = 0 \\ \Leftrightarrow \quad & A(\left(\alpha + \tfrac{1-\alpha}{2}\right) c - \phi) + \lambda_f - \lambda_L \tfrac{\partial L_\theta}{\partial f_\theta} = 0. \end{aligned} \tag{18}$$

Recall that $\frac{\partial L_\theta}{\partial f_\theta} > 0$. If $\left(\alpha + \frac{1-\alpha}{2}\right) c \geq \phi$ then we must have $\lambda_L > 0$ and it is optimal to set $f_\theta$ such that $L = 1$, i.e.,

$$\frac{A}{\phi - \left(\alpha + \frac{1-\alpha}{2}\right) f} = 1 \Leftrightarrow f = \frac{\phi - A}{\left(\alpha + \frac{1-\alpha}{2}\right)}.$$

If $\left(\alpha + \frac{1-\alpha}{2}\right) c < \phi$, then we must have $\lambda_f > 0$ for (18) to hold and $f_\theta = 0$. We then have $L = \frac{A}{\phi}$. Last, see that when $L = 1$, each operator's profit is positive iff $A \geq \phi - b$, and when $L = \frac{A}{\phi}$, each operator's profit is positive iff $A \geq \phi - \frac{\phi}{(\alpha+\frac{1-\alpha}{2})c} b$.

**Proof of Corollary 1**

When $\left(\alpha + \frac{1-\alpha}{2}\right) c \geq \phi$, operators optimally choose $L_\theta = 1$, which also maximizes total surplus (equal to $2b$) since consumers can always convert their digital money into cash and do not incur any loss. When $\left(\alpha + \frac{1-\alpha}{2}\right) c < \phi$, operators optimally choose $L_\theta = \frac{A}{\phi}$. In that case, a social planner could reach the maximal surplus $2b$ by setting $L_\theta = 1$ and leaving a rent $\phi - A$ to each agent. Each operator's profit would then be equal to $b - \phi + A$, which is positive when $A \geq \overline{A}$.

**Corollary 6** *Suppose there is no interoperability. Assume $A \geq \overline{A}$. If $\phi > \left(\alpha + \frac{1-\alpha}{2}\right) c$, the constrained optimum can be achieved by setting a tax $\tau = \phi - A$ to each operator and a subsidy $S = \phi - A$ to increase each agent's collateral.*

**Proof of Corollary 6**

When $\phi > (\alpha + \frac{1-\alpha}{2})c$, the constrained optimum can be achieved by setting a tax $\tau = \phi - A$ to each operator, and providing a subsidy $S = \phi - A$ to each agent. Indeed, with a subsidy $S$, agents' incentive compatibility constraint is written

$$L_\theta = \frac{A + S}{\phi - (\alpha + \frac{1-\alpha}{2}) f_\theta}. \tag{19}$$

And each operator's profit is

$$b - \left(\alpha + \frac{1-\alpha}{2}\right) c + \left(\alpha + \frac{1-\alpha}{2}\right) L_\theta (c - f_\theta) - \tau. \tag{20}$$

As before, to maximize its profit, each operator maximizes $L_\theta(c - f_\theta)$, or

$$\begin{aligned} \max_{f_\theta} \quad & (A + S)\frac{c - f_\theta}{\phi - \left(\alpha + \frac{1-\alpha}{2}\right) f_\theta} \\ \text{st.} \quad & f_\theta \geq 0 \\ \text{and} \quad & 1 - L_\theta \geq 0. \end{aligned} \tag{21}$$

Proceeding as before, when $\left(\alpha+\frac{1-\alpha}{2}\right)c<\phi$, each operator optimally sets $f_\theta=0$, inducing $L_\theta=\frac{A+S}{\phi}$, and obtains a profit equal to $b-\tau$. When $S=\phi-A$, this yields $L_\theta=1$ and each operator makes a positive profit if $A\geq\overline{A}$.

### Proof of Lemma 1

Consider each operator's objective when $L_1+L_2>1$.

$$\begin{aligned}\max_{f_\theta,\hat{f}_\theta}\quad & b-\alpha(1-L_\theta)c-\left(\alpha+\tfrac{1-\alpha}{2}\right)L_\theta f_\theta-\tfrac{1-\alpha}{2}(1-L_\theta)\hat{f}_\theta \\ \text{st}\quad & f_\theta\geq 0 \\ & \hat{f}_\theta\geq 0 \\ & 1-L_\theta\geq 0,\end{aligned} \tag{22}$$

where $L_\theta$ is defined by eq. 7. The FOCs of the Lagrangian associated to (22) are

$$\begin{aligned}&\alpha c\frac{\partial L_\theta}{\partial\hat{f}_\theta}-(\alpha+\frac{1-\alpha}{2})f_\theta\frac{\partial L_\theta}{\partial\hat{f}_\theta}-\frac{1-\alpha}{2}(1-L_\theta)+\frac{1-\alpha}{2}\hat{f}_\theta\frac{\partial L_\theta}{\partial\hat{f}_\theta}+\lambda_{\hat{f}\theta}-\lambda_L\frac{\partial L_\theta}{\partial\hat{f}_\theta}=0\\ \Leftrightarrow\ &-\frac{1-\alpha}{2}(1-L_\theta)+\frac{\partial L_\theta}{\partial\hat{f}_\theta}\left(\alpha c-(\alpha+\frac{1-\alpha}{2})f_\theta+\frac{1-\alpha}{2}\hat{f}_\theta-\lambda_L\right)+\lambda_{\hat{f}_\theta}=0\end{aligned} \tag{23}$$

$$-\left(\alpha+\frac{1-\alpha}{2}\right)L_\theta+\frac{\partial L_\theta}{\partial f_\theta}\left(\alpha c-(\alpha+\frac{1-\alpha}{2})f_\theta+\frac{1-\alpha}{2}\hat{f}_\theta-\lambda_L\right)+\lambda_{f_\theta}=0 \tag{24}$$

See first that we cannot have $\hat{f}_\theta>0$. Indeed, if $\hat{f}_\theta>0$, we have $\lambda_{\hat{f}_\theta}=0$. Then eq. 23 implies that

$$\frac{\partial L_\theta}{\partial\hat{f}_\theta}\left(\alpha c-(\alpha+\frac{1-\alpha}{2})f_\theta+\frac{1-\alpha}{2}\hat{f}_\theta-\lambda_L\right)>0.$$

Since $\frac{\partial L_\theta}{\partial\hat{f}_\theta}<0$, this implies $\left(\alpha c-(\alpha+\frac{1-\alpha}{2})f_\theta+\frac{1-\alpha}{2}\hat{f}_\theta-\lambda_L\right)<0$. Then eq. 24 implies that $\lambda_{f_\theta}>0$, hence $f_\theta=0$. If $\lambda_L=0$, $f_\theta=0$ contradicts $\left(\alpha c-(\alpha+\frac{1-\alpha}{2})f_\theta+\frac{1-\alpha}{2}\hat{f}_\theta-\lambda_L\right)<0$. If $\lambda_L>0$ and $L_\theta=1$, eq. 7 can only hold if $\hat{f}_{-\theta}>0$. Applying a symmetric reasoning to operator $-\theta$, $\hat{f}_{-\theta}>0$ can only hold if $L_{-\theta}=1$, which implies that eq. 7 cannot hold. We therefore have $\hat{f}_\theta=0$.

With $\hat{f}_\theta = 0$, using eq. 7, we have

$$\frac{\partial L_\theta}{\partial f_\theta} = \frac{\alpha + \frac{1-\alpha}{2}}{\left(\phi - (\alpha + \frac{1-\alpha}{2})f_\theta\right)^2} A. \tag{25}$$

Using eq. 25 into eq. 24 and rearranging terms, the FOC relative to $f_\theta$ is written

$$\frac{\alpha + \frac{1-\alpha}{2}}{\phi - (\alpha + \frac{1-\alpha}{2})f_\theta} A \left( \frac{\alpha c - \phi - \lambda_L}{\phi - (\alpha + \frac{1-\alpha}{2})f_\theta} \right) + \lambda_{f_\theta} = 0 \tag{26}$$

Since $\lambda_{f_\theta} \geq 0$ and $\lambda_L \geq 0$, eq. 26 can only hold if $\alpha c \geq \phi$, which implies that an equilibrium with $L_1 + L_2 > 1$ cannot exist if $\alpha c < \phi$. Also, when $\alpha c > \phi$, we must have $\lambda_L > 0$ and $L_1 = L_2 = 1$ is the only equilibrium. In that case, each operator's profit is equal to $b - \phi + A$ which is only positive if $A \geq \phi - b$. To complete the proof, see that when $\phi \leq \alpha c$, $\overline{A} = \phi - b$.

## Proof of Lemma 2

Assume now that $\phi > \alpha c$ and consider each operator's objective when $L_1 + L_2 \leq 1$.

$$\begin{aligned} \max_{f_\theta, \hat{f}_\theta} \quad & b - \left(\alpha(1 - L_\theta) + \tfrac{1-\alpha}{2}(1 - L_\theta - L_{-\theta})\right) c - \left(\alpha + \tfrac{1-\alpha}{2}\right) L_\theta f_\theta - \tfrac{1-\alpha}{2} L_{-\theta} \hat{f}_\theta \\ \text{st} \quad & f_\theta \geq 0 \\ & \hat{f}_\theta \geq 0 \\ & 1 - L_\theta - L_{-\theta} \geq 0, \end{aligned} \tag{27}$$

where $L_\theta$ is defined by eq. 10. The FOCs of the Lagrangian associated to (27) are

$$\frac{\partial L_\theta}{\partial f_\theta} \left( (\alpha + \frac{1-\alpha}{2})(c - f_\theta) - \lambda_L \right) - (\alpha + \frac{1-\alpha}{2}) L_\theta + \lambda_{f_\theta} = 0 \tag{28}$$

$$\frac{\partial L_{-\theta}}{\partial \hat{f}_\theta} \left( \frac{1-\alpha}{2}(c - \hat{f}_\theta) - \lambda_L \right) - \frac{1-\alpha}{2} L_{-\theta} + \lambda_{\hat{f}_\theta} = 0 \tag{29}$$

From eq. 10 we get

$$\frac{\partial L_\theta}{\partial f_\theta} = \frac{\alpha + \frac{1-\alpha}{2}}{\phi - (\alpha + \frac{1-\alpha}{2}) f_\theta - \frac{1-\alpha}{2}\hat{f}_{-\theta}} L_\theta \tag{30}$$

$$\text{and} \quad \frac{\partial L_{-\theta}}{\partial \hat{f}_\theta} = \frac{\frac{1-\alpha}{2}}{\phi - (\alpha + \frac{1-\alpha}{2}) f_{-\theta} - \frac{1-\alpha}{2}\hat{f}_{\theta}} L_{-\theta} \tag{31}$$

Using eq. 30 and eq. 31 into eq. 28 and eq. 29, the FOCs are written

$$L_\theta \left(\alpha + \frac{1-\alpha}{2}\right) \frac{(\alpha + \frac{1-\alpha}{2})c - \phi + \frac{1-\alpha}{2}\hat{f}_{-\theta} - \lambda_L}{\phi - (\alpha + \frac{1-\alpha}{2}) f_\theta - \frac{1-\alpha}{2}\hat{f}_{-\theta}} + \lambda_{f_\theta} = 0 \tag{32}$$

$$L_{-\theta} \frac{1-\alpha}{2} \frac{\frac{1-\alpha}{2}c - \phi + (\alpha + \frac{1-\alpha}{2}) f_{-\theta} - \lambda_L}{\phi - (\alpha + \frac{1-\alpha}{2}) f_{-\theta} - \frac{1-\alpha}{2}\hat{f}_{\theta}} + \lambda_{\hat{f}_\theta} = 0 \tag{33}$$

Can we have an equilibrium with $L_1 = L_2 = \frac{1}{2}$? Then, by eq. 10, agents' revenue must satisfy

$$(\alpha + \frac{1-\alpha}{2}) f_\theta + \frac{1-\alpha}{2}\hat{f}_{-\theta} = (\alpha + \frac{1-\alpha}{2}) f_{-\theta} + \frac{1-\alpha}{2}\hat{f}_{\theta} = \phi - 2A. \tag{34}$$

Assume that $\hat{f}_\theta = 0$. Then eq. 32 implies that $(\alpha + \frac{1-\alpha}{2})c \geq \phi$. Using eq. 34, replace $(\alpha + \frac{1-\alpha}{2}) f_{-\theta}$ by $\phi - 2A$ into eq. 33 to get $\phi - 2A - \phi + \frac{1-\alpha}{2}c \geq 0$, or $A \leq \frac{1-\alpha}{4}c$, which holds by Assumption 2. See next that the operator's profit is equal to $b - \frac{1}{2}\alpha c - \frac{1}{2}(\phi - 2A)$ which is positive iff $A \geq \frac{\alpha c + \phi}{2} - b \equiv \underline{A}$.

### Proof of Proposition 2

The proof of Lemma 1 established that $L_1 = L_2 = 1$ is the only equilibrium with $L_1 + L_2 > 1$ when $\phi \leq \alpha c$, and that this equilibrium does not exist if $\phi > \alpha c$. The proof of Lemma 2 established that an equilibrium with $L_1 = L_2 = \frac{1}{2}$ exists if $\alpha c < \phi \leq (\alpha + \frac{1-\alpha}{2})c$ and $A \geq \underline{A}$. We now prove that equilibria with $L_\theta \neq \{\frac{1}{2}; 1\}$ do not exist when $\alpha c < \phi \leq (\alpha + \frac{1-\alpha}{2})c$. From eq. 32 (the FOC with respect to $f_\theta$) we see that if $L_1 + L_2 < 1$, $\lambda_L = 0$, and we must have

$(\alpha + \frac{1-\alpha}{2})c \leq \phi$, which completes the proof of Proposition 2.

### Proof of Corollary 2

To establish (i), recall that when $\alpha c < \phi \leq (\alpha + \frac{1-\alpha}{2})c$ and $A > \overline{A}$, operators choose $L_1 = L_2 = 1$ without interoperability (Proposition 1), while they choose $L_1 = L_2 = \frac{1}{2}$ with interoperability (Proposition 2). See also that in that case, the equilibrium without interoperability corresponds to the constrained optimum (Corollary 1). We therefore conclude that interoperability reduces welfare (compared to the case without interoperability) and equilibrium liquidity with interoperability (equal to 1) is lower than the (constrained) optimal level (equal to 2).

To establish (ii), recall that when $\alpha c < \phi \leq (\alpha + \frac{1-\alpha}{2})c$ and $A < \overline{A}$, it is not possible for mobile money operators to function without interoperability (Proposition 1), while they do with interoperability (Proposition 2), so interoperability increases welfare. What is the constrained optimum level of liquidity in that case? The social planner maximizes consumer's surplus subject to the agents' incentive compatibility constraint and the operators' participation constraint. Recall that the incentive compatibility constraint sets a lower bound to the agent's payoff, equal to the agency rent $\phi L - A$, so that the social planner's objective can be expressed as (when $L \geq \frac{1}{2}$)

$$\begin{aligned} &\max_L 2(b - \alpha(1-L)c) \\ \text{st} \quad &\phi L - A \geq 0 \\ &b - \alpha(1-L)c - (\phi L - A) \geq 0 \\ &1 - L \geq 0, \end{aligned} \tag{35}$$

where $L$ is the (induced) level of liquidity of each agent. Ignoring constraints, the social planner would like to set $L = 1$, which, by the operators' participation constraint, is only possible if $b - \phi + A \geq 0$, i.e. $A \geq \overline{A}$. Next, when $A < \overline{A}$, the social planner maximizes welfare by setting $L = \frac{b-\alpha c+A}{\phi-\alpha c}$ so that operators make zero profit. See that $\frac{b-\alpha c+A}{\phi-\alpha c} > \frac{1}{2}$ when $\phi > \alpha c$ and $A \geq \underline{A}$, which establishes ii).

To establish (iii), recall that when $\phi \leq \alpha c$, the same equilibrium $L_1 = L_2 = 1$ (which corresponds to the constrained optimum) is sustained with and without interoperability when $A \geq \overline{A}$, and operators are not active when $A < \overline{A}$.

### Proof of Corollary 3

When $\phi \leq \left(\alpha + \frac{1-\alpha}{2}\right) c$, the equilibrium outcome always entails $L_\theta \geq \frac{1}{2}$. Recall from (35) that the operators' joint profit is written

$$2b - \alpha(1 - L_\theta)c - \alpha(1 - L_{-\theta})c - \phi L_\theta + A - \phi L_{-\theta} + A.$$

Observe that the derivative with respect to $L_\theta$ has the sign of $\alpha c - \phi$. This implies that if $\phi \leq \alpha c$, the equilibrium outcome ($L_1 = L_2 = 1$) maximizes the operators' joint profit. When $\phi > \alpha c$, firms cannot jointly increase profit by increasing liquidity beyond $\frac{1}{2}$ because all the gains from diversification are exhausted: consumers always obtain liquidity when their shocks are idiosyncratic.

### Proof of Lemma 3

Assume that moral hazard is severe, i.e., $\left(\alpha + \frac{1-\alpha}{2}\right) c < \phi$. Recall from the proof of Lemma 2 that when $L_1 + L_2 \leq 1$, each operator's objective is defined by (27), and the FOCs are given by eq. 32 and eq. 33.

Let us first establish the existence of an equilibrium with $L_1 = L_2 = \frac{1}{2}$. Then, agents' revenue must satisfy eq. 34. We know from the proof of Lemma 2 that for this equilibrium to exist when moral hazard is severe, we must have $\hat{f}_\theta > 0$. Then eq. 33 is written

$$\frac{1-\alpha}{2}c - \phi + (\alpha + \frac{1-\alpha}{2})f_{-\theta} - \lambda_L = 0. \tag{36}$$

Given that $\phi > \left(\alpha + \frac{1-\alpha}{2}\right)c$, eq. 36 implies that $(\alpha + \frac{1-\alpha}{2})f_{-\theta} > \phi - \frac{1-\alpha}{2}c > 0$. The FOC wrt $f_{-\theta}$ then implies that $\frac{1-\alpha}{2}\hat{f}_\theta > \phi - \left(\alpha + \frac{1-\alpha}{2}\right)c > 0$. For the conditions on $f_{-\theta}$ and $\hat{f}_\theta$ to be consistent with eq. 34 we must have

$$\phi - 2A > \phi - \frac{1-\alpha}{2}c + \phi - \left(\alpha + \frac{1-\alpha}{2}\right)c \Leftrightarrow \phi < c - 2A.$$

Last, recall that operators' profits are positive with $L_1 = L_2 = \frac{1}{2}$ iff $A \geq \underline{A}$. It is thus possible to sustain an equilibrium such that $L_1 = L_2 = \frac{1}{2}$ with $f_\theta > 0$ and $\hat{f}_\theta > 0$ iff $A \geq \underline{A}$ and $\left(\alpha + \frac{1-\alpha}{2}\right)c < \phi < c - 2A$.

Assume next that $f_\theta = \hat{f}_\theta = 0$. See that the FOCs (32) and (33) can only hold if $\left(\alpha + \frac{1-\alpha}{2}\right)c < \phi$. Then by eq. 10, agents choose the minimum level of liquidity, ie. $L_1 = L_2 = \frac{A}{\phi}$. Each operator's profit is then equal to

$$b - \left(\alpha(1 - \frac{A}{\phi}) + \frac{1-\alpha}{2}(1 - \frac{2A}{\phi})\right)c = b - \left(\alpha + \frac{1-\alpha}{2} - \frac{A}{\phi}\right)c,$$

which is positive iff $A \geq \phi\left(\alpha + \frac{1-\alpha}{2} - \frac{b}{c}\right) \equiv \hat{A}$. Thus an equilibrium with $L_1 = L_2 = \frac{A}{\phi}$ can be sustained iff moral hazard is severe and $A \geq \hat{A}$.

### Proof of Lemma 4

The proof of Lemma 1 establishes that we cannot have an equilibrium with $L_1 + L_2 > 1$ when $\phi > \alpha c$. Turning to equilibria such that $L_1 + L_2 \leq 1$, the proof of Lemma 3 shows that we cannot sustain an equilibrium with $L_1 = L_2 = \frac{1}{2}$ if $\phi > c - 2A$, but that we can sustain an equilibrium with $L_1 = L_2 = \frac{A}{\phi}$. To prove Lemma 4, we need to establish that no equilibrium with $\frac{A}{\phi} < L < \frac{1}{2}$ can be sustained when $\phi > c - 2A$.

Recall that operator $\theta$'s FOCs are eq. 32 and eq. 33. From the agents' incentive compatibility constraint (10), $L_\theta > \frac{A}{\phi}$ implies that $f_\theta > 0$ or $\hat{f}_{-\theta} > 0$. Assume for instance that $f_\theta > 0$.[9] Then, eq. 32 implies

$$\frac{1-\alpha}{2}\hat{f}_{-\theta} = \phi - \left(\alpha + \frac{1-\alpha}{2}\right)c. \tag{37}$$

Since $\hat{f}_{-\theta} > 0$, the FOC wrt $\hat{f}_{-\theta}$ implies

$$\left(\alpha + \frac{1-\alpha}{2}\right)f_\theta = \phi - \frac{1-\alpha}{2}c. \tag{38}$$

Using the agent's incentive compatibility constraint (10), $L < \frac{1}{2}$ implies

$$\left(\alpha + \frac{1-\alpha}{2}\right)f_\theta + \frac{1-\alpha}{2}\hat{f}_{-\theta} < \phi - 2A,$$

which, using eq. 37 and eq. 38, yields $\phi < c - 2A$. Therefore, the only possible equilibrium when $\phi > c - 2A$ is $L_1 = L_2 = \frac{A}{\phi}$, and it can only be sustained if $A \geq \hat{A}$.

### Proof of Proposition 3

To establish Proposition 3, compare operators' profit when $L_1 = L_2 = \frac{1}{2}$ to their profit when $L_1 = L_2 = \frac{A}{\phi}$ in the case when multiple equilibria coexist. Using operators' profit function (13) and agents' incentive compatibility constraint (10), the equilibrium with $L_1 = L_2 = \frac{1}{2}$ dominates the equilibrium with $L_1 = L_2 = \frac{A}{\phi}$ if

$$\begin{aligned} & b - \tfrac{1}{2}(\alpha c + \phi) + A > b - (\alpha + \tfrac{1-\alpha}{2} - \tfrac{A}{\phi})c \\ \Leftrightarrow \quad & \tfrac{c-\phi}{2} > A(\tfrac{c}{\phi} - 1), \end{aligned}$$

which always holds when $\left(\alpha + \frac{1-\alpha}{2}\right)c < \phi \leq c - 2A$.[10] The rest of the proposition follows from Lemma 3 and Lemma 4.

[9] The same reasoning applies if one assumes first that $\hat{f}_\theta > 0$.

[10] When $\phi \leq c - 2A$ there also exists an unstable equilibrium with $\frac{A}{\phi} < L_\theta < \frac{1}{2}$ as discussed in Footnote 8. In that equilibrium, operators' profit is also lower than when $L_1 = L_2 = \frac{1}{2}$.

**Proof of Corollary 4**

Assume that $\phi > c - 2A$ and $A \geq \hat{A}$. Then the only equilibrium entails $L_1 = L_2 = \frac{A}{\phi}$, with $f_\theta = \hat{f}_\theta = 0$. Could firms do better by cooperating (i.e. committing to set higher fees)? This is equivalent to maximizing the firms' joint profit. From (13), firms' joint profit is

$$\pi = b - \left(\alpha(1-L_1) + \frac{1-\alpha}{2}(1-L_1-L_2)\right)c - \left(\alpha + \frac{1-\alpha}{2}\right)L_1 f_1 - \frac{1-\alpha}{2}L_2\hat{f}_1$$
$$+b - \left(\alpha(1-L_2) + \frac{1-\alpha}{2}(1-L_1-L_2)\right)c - \left(\alpha + \frac{1-\alpha}{2}\right)L_2 f_2 - \frac{1-\alpha}{2}L_1\hat{f}_2$$

We then have

$$\begin{aligned}\frac{\partial\pi}{\partial f_1} &= \frac{\partial L_1}{\partial f_1}\left(\left(\alpha + \frac{1-\alpha}{2}\right)(c-f_1) + \frac{1-\alpha}{2}(c-\hat{f}_2)\right) - \left(\alpha + \frac{1-\alpha}{2}\right)L_1 \\ &= \left(\alpha + \frac{1-\alpha}{2}\right)L_1\left(\frac{\left(\alpha+\frac{1-\alpha}{2}\right)(c-f_1)+\frac{1-\alpha}{2}(c-\hat{f}_2)}{\phi-\left(\alpha+\frac{1-\alpha}{2}\right)f_1-\frac{1-\alpha}{2}\hat{f}_2} - 1\right) \\ &= \frac{\left(\alpha+\frac{1-\alpha}{2}\right)L_1}{\phi-\left(\alpha+\frac{1-\alpha}{2}\right)f_1-\frac{1-\alpha}{2}\hat{f}_2}(c-\phi),\end{aligned}$$

which is positive as long as long as $\phi < c$.

We obtain similarly that

$$\frac{\partial\pi}{\partial\hat{f}_1} = \frac{1-\alpha}{2}L_2\frac{(c-\phi)}{\phi-\left(\alpha+\frac{1-\alpha}{2}\right)f_2-\frac{1-\alpha}{2}\hat{f}_1},$$

which is positive as long as long as $\phi < c$.

Hence, when $\phi > c - 2A$, an increase in $f_1$ and $\hat{f}_1$ strictly increases joint profits.

**Proof of Corollary 5**

Recall from Proposition 1 that when $\phi > \left(\alpha + \frac{1-\alpha}{2}\right)c$, the only equilibrium when operators are active entails $L_1 = L_2 = \frac{A}{\phi}$ without interoperability. Next, see that when liquidity is scarce ($L_1 + L_2 < 1$), making agents interoperable always increases consumers' utility. Indeed, without interoperability, consumers' utility for given levels of liquidity $L_\theta$ and $L_{-\theta}$ is

$$b - \left(\alpha + \frac{1-\alpha}{2}\right)(1 - L_\theta)c,$$

while with interoperability consumers' utility is

$$b - \left(\alpha(1 - L_\theta) + \frac{1-\alpha}{2}(1 - L_\theta - L_{-\theta})\right)c.$$

Comparing Proposition 1 and Proposition 3 leads to (i) and (ii). To establish (iii), recall from Proposition 2 that when $\phi > \alpha c$, the constrained optimum entails setting $L_1 = L_2 = \frac{b-\alpha c+A}{\phi-\alpha c} > \frac{1}{2}$, when $A \geq \underline{A}$, and not to operate mobile money services otherwise.

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