

Creti, Anna; Verdier, Marianne

**Working Paper**

## Fraud, investments and liability regimes in payment platforms

ECB Working Paper, No. 1390

**Provided in Cooperation with:**

European Central Bank (ECB)

*Suggested Citation:* Creti, Anna; Verdier, Marianne (2011) : Fraud, investments and liability regimes in payment platforms, ECB Working Paper, No. 1390, European Central Bank (ECB), Frankfurt a. M.

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EUROPEAN CENTRAL BANK

EUROSYSTEM

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**CONFERENCE ON THE FUTURE OF RETAIL  
PAYMENTS: OPPORTUNITIES AND CHALLENGES**

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**WORKING PAPER SERIES**

**NO 1390 / OCTOBER 2011**

**FRAUD, INVESTMENTS  
AND LIABILITY  
REGIMES IN PAYMENT  
PLATFORMS**

by Anna Creti  
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by Anna Creti<sup>1</sup>  
and Marianne Verdier<sup>2</sup>

NOTE: This Working Paper should not be reported as representing the views of the European Central Bank (ECB). The views expressed are those of the authors and do not necessarily reflect those of the ECB.

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<sup>1</sup> Université Paris Ouest Nanterre and Ecole Polytechnique. Economix, Bâtiment G, bureau 604, 200 avenue de la République, 92001 Nanterre Cedex, France; e-mail: [acretibettoni@u-paris10.fr](mailto:acretibettoni@u-paris10.fr).

<sup>2</sup> Université Paris Ouest Nanterre, Economix, Bâtiment T, bureau 234, 200 avenue de la République, 92001 Nanterre Cedex, France; e-mail: [marianne.verdier@u-paris10.fr](mailto:marianne.verdier@u-paris10.fr).

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**Address**

Kaiserstrasse 29  
60311 Frankfurt am Main, Germany

**Postal address**

Postfach 16 03 19  
60066 Frankfurt am Main, Germany

**Telephone**

+49 69 1344 0

**Internet**

<http://www.ecb.europa.eu>

**Fax**

+49 69 1344 6000

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ISSN 1725-2806 (online)



## **The future of retail payments: opportunities and challenges**

The way people pay is continuously changing, as a result of innovations in retail payments, improvements in efficiency and regulatory changes. This changing environment creates opportunities for some and challenges for others in the retail payments sector. The impact of these changes on the future of retail payments was the main theme of the biannual retail payments conference organised by the European Central Bank (ECB), this time in cooperation with the Oesterreichische Nationalbank (OeNB), on 12 and 13 May 2011 in Vienna. More than 200 high-level policymakers, financial sector representatives, academics and central bankers from Europe and other regions attended this conference, reflecting the topicality of and interest in the retail payments market.

The aim of the conference was to better understand current developments in retail payment markets and to identify possible future trends, by bringing together policymaking, research activities and market practice. A number of key insights and conclusions emerged. The Single Euro Payments Area (SEPA) project is recognised as being on the right track, even though some further work needs to be done in the areas of standardisation of card payments and migration towards SEPA instruments. The European Commission's proposal for a regulation setting an end date for migration to SEPA credit transfers and SEPA direct debits is welcomed. For SEPA to be a success, it is essential that users are involved, in order to ensure acceptance of the SEPA instruments. Moreover, innovations in retail payments are taking place more rapidly than ever, and payment service providers and regulators need to adapt quickly to this changing business environment.

We would like to thank all participants in the conference for the very interesting discussions. In particular, we would like to acknowledge the valuable contributions and insights provided by all speakers, discussants, session chairpersons and panellists, whose names can be found in the conference programme. Their main statements are highlighted in the ECB-OeNB official conference summary. Six

papers related to the conference have been accepted for publication in this special series of the ECB Working Papers Series.

Behind the scenes, a number of colleagues from the ECB and the OeNB contributed to both the organisation of the conference and the preparation of these conference proceedings. In alphabetical order, many thanks to Nicola Antesberger, Stefan Augustin, Michael Baumgartner, Christiane Burger, Stephanie Czák, Susanne Drusany, Henk Esselink, Susan Germain de Urday, Monika Hartmann, Monika Hempel, Wiktor Krzyzanowski, Thomas Lammer, Tobias Linzert, Alexander Mayrhofer, Hannes Nussdorfer, Simonetta Rosati, Daniela Russo, Wiebe Ruttenberg, Heiko Schmiedel, Doris Schneeberger, Francisco Tur Hartmann, Pirjo Väkevainen and Juan Zschiesche Sánchez.

Gertrude Tumpel-Gugerell

Former member of the Executive Board  
European Central Bank

Wolfgang Duchatzek

Vice Governor  
Oesterreichische Nationalbank

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## Abstract

In this paper, we discuss how fraud liability regimes impact the price structure that is chosen by a monopolistic payment platform, in a setting where merchants can invest in fraud detection technologies. We show that liability allocation rules distort the price structure charged by platforms or banks to consumers and merchants with respect to a case where such a responsibility regime is not implemented. We determine the allocation of fraud losses between the payment platform and the merchants that maximises the platform's profit and we compare it to the allocation that maximises social welfare.

**JEL Codes:** G21, L31, L42.

**Keywords:** Payment card systems, interchange fees, two-sided markets, fraud, liability.



# 1 Introduction:

The development of electronic data exchange in the banking industry has generated an increase in fraud and cybercrime. For instance, in the United-States, according to the Consumer Sentinel Network (CSN), 1.2 million complaints of consumer fraud have been recorded in 2008.<sup>1</sup> As a consequence, banks can make substantial losses because of fraudulent use of payment cards, which differ across countries and payment systems (See table 1).

*Table 1: Loss rate per \$100 payment card transaction value in several countries<sup>2</sup>*

Country	Spain	Australia	France	UK	US
Losses rate	2.24¢	2.39¢	5¢	9.12¢	9.2¢

Minimizing the occurrence of fraud in electronic payment systems requires costly efforts from all the participants to a transaction: platforms, banks, consumers and merchants.<sup>3</sup> For instance, consumers have to protect their personal data and to report the fraud rapidly once it occurs, whereas platforms, banks and merchants may invest substantial amounts in fraud detection technologies.<sup>4</sup> These efforts in fraud prevention depend on the expected amount of losses and their allocation, which responds to several liability rules, determined either by public laws or by private network rules. Currently, in most payment card systems, consumers hardly bear meaningful liability for fraudulent use of their payment card, because they are protected both by financial regulations, which are public laws (e.g. TILA and regulation Z in the United-States)<sup>5</sup>, and by the 'zero liability rule', which has been privately adopted by several payment networks. It follows that, in most payment systems, the burden of fraud losses is shared between banks or platforms and merchants.<sup>6</sup> The allocation of liability between banks and merchants

<sup>1</sup>Source: Consumer Sentinel Network Data Book for January-December 2008, Federal Trade Commission, February 2009. This report highlights that credit card fraud is the most common form of reported identity theft amounting at 20% of the reported fraudulent transactions.

<sup>2</sup>Source: Richard Sullivan (2010), Federal Reserve Bank of Kansas City, 'The Changing Nature of Payment Card Fraud: Issues for Industry and Public Policy'.

<sup>3</sup>According to the Federal Reserve Board, in the United-States, "On average, by transaction type, issuers incurred 2.2¢ per signature-debit transaction for fraud-prevention and data-security activities and 1.2¢ per PIN-debit transaction. Similarly, networks incurred 0.7¢ per signature-debit transaction for fraud-prevention and data-security activities and 0.6¢ per PIN-debit transaction. Finally, acquirers incurred 0.4¢ per signature-debit transaction for fraud-prevention and data-security activities and 0.3¢ per PIN-debit transaction.". Source: Federal Register / Vol. 75, No. 248 / Tuesday, December 28, 2010 / Proposed Rules.

<sup>4</sup>According to a survey conducted by the Federal Reserve Board in the United-States, issuers engage in various fraud-prevention activities such as "transaction monitoring and fraud risk scoring systems that may trigger an alert or call to the cardholder in order to confirm the legitimacy of a transaction". "Merchants also have fraud-prevention data-security costs, including costs related to compliance with payment card industry data-security standards (PCI-DSS) and other tools to prevent fraud, such as address verification services or internally developed fraud screening models, particularly for card-not-present transactions".

<sup>5</sup>For a comparison of consumer protection laws across various countries, see Appendix A.

<sup>6</sup>For instance, in France, according to the "Observatoire de la sécurité des cartes de paiement", fraud losses have been shared in 2009 between banks (41.1%) and merchants (53.5%). Merchants have been held liable mainly for fraud on internet transactions. Consumers were held liable for only 2.3% of the fraud losses. According to

generally depends on private rules that are chosen by payment platforms. Some networks may even use liability rules to provide merchants with incentives to adopt new technologies. For instance, MasterCard and Visa used liability shift measures to induce merchants to adopt fraud prevention technologies on the internet (MasterCard SecureCode<sup>TM</sup> and Visa 3-D Secure<sup>TM</sup> respectively).<sup>7</sup> Interestingly, if the merchant implements the 3-D Secure<sup>TM</sup> technology, the issuer becomes liable for fraud losses for all eCommerce transactions that went through the 3-D Secure<sup>TM</sup> process.

This paper addresses two major issues related to fraud in payment systems: What is the incidence of fraud liability regimes on the price structure that is charged by payment platforms? How do private liability regimes differ from the socially optimal regime that would be implemented by a social planner? In particular, we analyse whether private network rules provide merchants with sufficient incentives to invest in fraud detection technologies and whether these rules generate the socially optimal allocation of fraud losses.

In our framework, we use a broad definition of fraud, which is the use of an electronic payment instrument (or its information) by a person other than its owner, to obtain goods and services without authority for such use.<sup>8</sup> We consider a monopolistic proprietary payment platform that provides an electronic payment instrument to consumers and merchants. Consumers and merchants decide whether or not to adopt the electronic payment instrument based on the price of the payment instrument and on the expected loss that they incur in case of fraudulent transaction. Fraudulent transactions are detected with some probability that is positively related to merchants' investments in fraud prevention technologies. If a fraud is detected, then the participants do not make losses.

Our results highlight the following trade-off for the payment platform. When the level of liability for merchants increases, the number of merchants who accept the electronic payment instrument falls, but merchants tend to invest more in fraud detection technologies, which increases consumers' willingness to use the electronic payment method. The payment platform trades off between increasing the level of liability to minimize the expected loss on fraudulent transaction and maximizing the transaction volume by encouraging merchants and consumers

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Furletti (2005), in the United-States, "consumers of credit cards are shielded from nearly \$3 billion in fraud losses each year". According to a more recent survey conducted by the Federal Reserve Board in the US, in 2009, across all types of debit card transactions, 57% of fraud losses were borne by issuers and 43% were borne by merchants. Source: Federal Reserve Register, vol. 75 n°248, 2010.

<sup>7</sup>These services provide Internet merchants with the ability to verify their consumers' true identities through a secure, electronic, non 'face-to-face' authentication process.

<sup>8</sup>Our model does not enable us to distinguish which type of fraud is implemented by the fraudster. We consider any type of fraud that can be impeded by merchant investment. For instance, data breaches and phishing do not depend on merchants' investments (rather on platform's investment). On the contrary, identity theft can be avoided by the merchant's effort to verify the consumer's identity.

to accept the electronic payment instrument. In the short term, the existence of a fraud liability regime affects the pricing structure of the payments system. With respect to the standard price structure in two-sided markets (Rochet-Tirole, 2003), the price structure that we obtain takes into account the platform's trade-off between maximising its profit and minimizing the expected loss on fraudulent transactions. If the zero liability rule for consumers applies, the allocation of fraud losses that is chosen by the payment platform does not place enough liability on merchants to maximise social welfare. Therefore, liability regimes can be used by monopolistic payment platforms to extract rents from merchants, as it enables them to charge higher prices. We also find that this result does not hold if investments are shared between the platform and the merchants.

We also determine the incidence of the liability regime on the choice of the interchange fee. We find that, if the issuers are imperfectly competitive, whereas the acquirers are perfectly competitive, the profit maximising interchange fee decreases with the level of liability that is borne by merchants.

The rest of the paper is organized as follows. In Section 2, we summarize the literature related to our study. In Section 3, we develop a theoretical model to analyze the optimal allocation of fraud losses between the payment platform and the merchants. In section 4, we determine the profit maximising allocation of fraud losses. In section 5, we study the welfare maximising allocation of fraud losses. In section 6, we analyze the role of interchange fees. In section 7, we extend the model by studying the optimal allocation of investments between the payment platform and the merchants. Finally, we conclude.

## 2 Related Literature

To our knowledge, this paper is the first attempt to model fraud detection technologies and liability regimes in the literature on payment systems. Our approach thus relies on three different strands of literature: the literature on payment platforms, on investment in two-sided markets, and finally the literature on liability issues in law and economics.

Most papers on payment systems focus on explaining the divergence between the profit maximising price structure that is charged by payment platforms and the price structure that maximises social welfare (see Chakravorti (2010) for a review). In particular, several papers aim at determining whether payment platforms charge excessive interchange fees when they maximise banks' joint profit (as surveyed by Verdier, 2011). Our paper contributes to this literature by extending Rochet-Tirole (2003) to study how the allocation of the expected fraud loss between the platform and the merchants changes the profit-maximising price structure.

The literature on investment in two-sided markets is scarce. For instance, Verdier (2010) determines the optimal price structure of a payment card platform in which monopolistic banks can invest to improve the quality of the payment service. Her model studies how investments should be allocated between monopolistic banks in four-party payment platforms. In particular, she finds that a reduction of interchange fees can improve the allocation of investments by encouraging acquirers to invest, when investments increase consumers' demand. Our model departs from that paper, as we consider a monopolistic proprietary payment platform, and we focus on the optimal allocation of fraud losses between the platform and the merchants. The four-party model is used in section 5 of our paper, where we show that the profit maximizing interchange fee decreases with the level of liability borne by merchants. The only paper that considers merchants' investments in two-sided platforms is the paper by Peitz and Belleflamme (2010), who study the effect of the intermediation mode (for-profit competing platforms versus free access) on sellers' investment, in a model where sellers' investment increase the buyers' utility of belonging to the platform. They show that for-profit intermediation may lead to overinvestment when innovations increase buyers' surplus, because competing intermediaries react by lowering the access fees on the seller side. Our focus is different from theirs, as we take the intermediation mode as given, and focus on the impact of liability rules on sellers' investments incentives.

Our model is also related to the vast literature on tort law whose main goal is to enhance socially optimal decisions on the level of precaution (Brown, 1973). More precisely, our framework shares the same background of ex post liability regimes, while neglecting the problem of non compliance and enforcement of ex ante regulation.<sup>9</sup> In this context, strict liability allocates the losses to the injurer by entitling the victim to compensation, whereas no liability allocates the losses to the victim, by denying the right to compensation (Landes and Posner, 1987). Indeed, liability provides incentives for precaution.<sup>10</sup> We extend this argument to the case of a three party system interrelated through network effects, which is uncommon in law and economics models. In fact, in our framework, the price of a transaction implies not only a choice for a consumer, which generates a loss risk (as also pointed out by law scholars like Cooter and Robin, 1987), but also a pricing strategy by the platform and an incentive for the merchant to invest in fraud detection.

<sup>9</sup>Ex ante regulation is meant to prevent accidents from occurring through the enforcement of minimum safety standards or compliance restrictions. Ex post liability, exercised after an accident has occurred, is a legal device that enables victims to sue for damages, forcing injurers to internalize part of the harm they cause.

<sup>10</sup>When both parties have to take precaution in order to avoid an accident, strict liability creates no incentives for victim precaution, while no liability would shift the entire residual liability on the victim, inducing optimal victim care. It follows that strict liability and no liability can give incentives to take efficient precaution only to one party, respectively either the injurer or the victim (Dari-Mattiacci, Parisi, 2006).

### 3 The model

We build a model in which a monopolistic payment platform offers an Electronic Payment Instrument (hereafter the EPI) to consumers and merchants. We extend Rochet and Tirole (2003) along several dimensions. We consider that there is an exogenous probability that the EPI is fraudulently used, in a setting where merchants can invest in fraud detection technologies. We define fraud as the use of an electronic payment instrument (or its information) by a person other than its owner, to obtain goods and services without authority for such use. The fraud entails a lump sum loss which does not depend on the transaction value. Our framework enables us to determine how fraud liability should be allocated between the participants to maximise the platform's profit. It also enables us to compare the private optimal allocation to the one that maximises social welfare.

**Payment system and allocation of fraud:** A monopolistic payment platform provides an electronic payment instrument (e.g. the payment card) to consumers and merchants. The marginal cost of processing a transaction is denoted by  $c$ . Consumers and merchants pay transaction fees to the platform, which are denoted by  $f$  and  $m$  respectively.

When consumers use the EPI, there is an exogenous probability  $x \in (0, 1)$  that the payment instrument is intercepted by fraudsters.<sup>11</sup> There is also a probability  $q \in [0, 1]$  that the fraud is detected, which depends on merchants' investments. If the fraud is not detected, all the participants to the transaction make an exogenous loss that we denote by  $L > 0$ . The loss is allocated between the consumer, the merchant and the payment platform as follows: the consumer (or buyer  $B$ ) and the merchant (or seller  $S$ ) bear respectively a share  $\alpha_B$  and  $\alpha_S$  of the loss, where  $\alpha_S + \alpha_B \in [0, 1]$ . The rest of the loss,  $\alpha_P = 1 - (\alpha_S + \alpha_B)$ , is borne by the payment platform. We assume that the parameter  $\alpha_B$  is determined by public laws and we consider it as exogenous to the model. In particular, if  $\alpha_B = 0$ , the zero liability rule applies for consumers. The parameter  $\alpha_S$  is privately chosen by the payment platform.<sup>12</sup> We choose to normalize the fraud on cash payments to zero.<sup>13</sup>

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<sup>11</sup>The assumption that  $x$  is exogenous is made for simplicity. Indeed, endogenizing  $x$  would introduce another trade-off for the merchant. Higher investments in fraud detection technologies have two effects on hackers' incentives to fraud. On the one hand, higher investments in fraud increase the volume of transactions, which increases the hackers' incentives to commit fraud. On the other hand, higher investments increase the probability that a fraud is detected, which may discourage hackers to commit fraud.

<sup>12</sup>In our model, we do not study how the losses are allocated between banks and the payment platform. In practice, payment platforms design rules to allocate the losses between issuing and acquiring banks and also to allocate the losses between banks and the platform itself. This issue would deserve a separate study. We reintroduce banks in section 4 and choose to focus on the role of interchange fees in fraud prevention issues.

<sup>13</sup>Introducing the probability that a fraudulent payment is made by cash would not change the trade-offs that we highlight in our model. We would only have to modify assumption (A2) to take into account the losses that are due to fraud on cash payments.



**Merchants:** We consider local monopolist merchants that supply the same good to consumers. The marginal cost of producing the good is denoted by  $d$  and the price of the good is denoted by  $p$ . We assume that the non-discrimination rule holds, such that a merchant cannot not charge a price that depends on the payment method. Each merchant can decide whether or not to accept the electronic payment instrument. If he decides to accept the EPI, the merchant may invest an amount  $e_S$  in fraud detection technologies. Investment to improve fraud detection costs  $C_S(e_S)$  to the merchant, where  $C_S(e_S)$  is paid per transaction,  $C'_S(e_S) \geq 0$ ,  $C''_S(e_S) \geq 0$  and  $C'''_S(e_S) \geq 0$ . Merchant's investments increase the probability  $q$  that a fraudulent transaction is detected, that is, we assume that  $dq/de_S > 0$  for all  $e_S > 0$ . We also assume that  $d^2q/d^2e_S \leq 0$  for all  $e_S \geq 0$  and that  $d^3q/d^3e_S \leq 0$ .<sup>14</sup> The amount invested in fraud detection technologies is common knowledge, such that banks and consumers are aware of the security measures implemented by the merchants.<sup>15</sup>

By accepting the EPI, each merchant obtains a transaction benefit that we denote by  $b_S$ , where  $b_S > 0$ . As in Rochet and Tirole (2003), we assume that merchants are heterogenous over their transaction benefit  $b_S$  which is distributed over  $[\underline{b}_S, \overline{b}_S]$  according to the probability density  $h_S$  and the cumulative  $H_S$ . We assume that  $h'_S \geq 0$  to ensure demand (quasi) concavity. We normalize the benefit of accepting cash to zero. The merchant pays a fee  $m$  to the payment platform each time a consumer pays with the EPI and bears the cost of investing in fraud detection technologies. We also assume that merchants are risk neutral.

**Consumers:** Consumers obtain a surplus  $v > 0$  if they buy the good that is supplied by the merchants. They are assumed to hold two payment instruments: cash and the Electronic Payment Instrument. Each consumer is randomly matched to one merchant and chooses between paying cash or paying with the EPI, if the merchant accepts the EPI. We assume that consumers are risk neutral and that they can observe merchants' investment in fraud detection technologies before deciding whether or not to use the EPI.

If he pays with the EPI, the consumer obtains a transaction benefit  $b_B$  which is distributed over  $[\underline{b}_B, \overline{b}_B]$  according to the probability density  $h_B$  and the cumulative  $H_B$ . We assume that  $h'_B \geq 0$  for concavity to hold. The consumer pays a fee  $f$  to the payment platform, and anticipates that, with some probability  $x(1 - q)$ , he bears a share  $\alpha_B$  of the loss  $L$ , because the EPI is fraudulently used without being detected.<sup>16</sup> The benefit of paying cash is normalized

<sup>14</sup>The assumption that  $d^2q/d^2e_S \leq 0$  ensures that the second-order condition is verified when the merchant chooses its level of investment. The assumption that  $d^3q/d^3e_S \leq 0$  ensures that the second-order condition is verified when the platform maximises its profit.

<sup>15</sup>Merchants can inform consumers about their efforts to fight fraud. For instance, online sellers can communicate on the use of a software or a specific technology that improves consumer authentication.

<sup>16</sup>We rule out the possibility that consumers do not anticipate perfectly the detection probability. However,



to zero. It follows that, if a consumer can choose between cash and the EPI, under the non-discrimination rule, a consumer wishes to use the EPI if and only if

$$b_B - f - \alpha_B x(1 - q)L \geq 0, \quad (1)$$

that is, if his transaction benefit is higher than the cost of the transaction fee and the expected fraud loss.

#### **Additional assumptions:**

(A1) The hazard rate  $\frac{h_B(x)}{1 - H_B(x)}$  is increasing.

(A2) In equilibrium,  $\min \left\{ v - d, \frac{1}{xL\alpha_B} \right\} \geq \frac{h_B(f + \alpha_B(1 - q)xL)}{1 - H_B(f + \alpha_B(1 - q)xL)}$ .

Assumptions (A1) is similar to Wright (2002) and standard in the literature on payment cards. Assumption (A2) ensures that:

(i) consumers obtain a much higher surplus from buying the good than from making a transaction with the Electronic Payment Instrument.<sup>17</sup>

(ii) the amount of the expected share of the fraud loss for consumers is not too high, such that it does not exceed the surplus that consumers obtain from making a transaction.<sup>18</sup>

#### **Timing:**

The timing of the game is as follows:

1. The platform chooses the liability level  $\alpha_S$  and the transaction fees  $f$  and  $m$ .
2. The merchants decide whether or not to accept the EPI and how much to invest in fraud detection technologies. They also choose the price of the good  $p$ .
3. Each consumer is matched randomly to one merchant. Consumers decide on whether or not to buy the good and how to pay for the good (either by cash or with the EPI).

In the following section, we look for the subgame perfect equilibrium and solve the game by backward induction.

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in practice, consumers may overreact to the risk of fraud. This can be studied in our framework by doing some comparative statics about  $\alpha_B$ .

<sup>17</sup>Part (i) of Assumption (A2) is standard in the literature (see Wright (2002)). Formally, this corresponds to the Assumption that  $v - d \geq h_B(f + \alpha_B(1 - q)xL)/(1 - H_B(f + \alpha_B(1 - q)xL))$ .

<sup>18</sup>Part (ii) of Assumption (A2) is new, as our paper is the first to model the incidence of fraud losses on consumers and merchants' payment choices and platform prices. Formally, this corresponds to the Assumption that:  $(1/xL\alpha_B) \geq h_B(f + \alpha_B(1 - q)xL)/(1 - H_B(f + \alpha_B(1 - q)xL))$ .

## 4 The equilibrium:

### 4.1 Stage 3: consumer payment decisions

We start by determining the probability that a consumer wishes to use the Electronic Payment Instrument. Consider a consumer whose transaction benefit is  $b_B \in [\underline{b}_B, \overline{b}_B]$ . This consumer is randomly matched to one merchant, who may or may not accept the EPI. If the merchant accepts the EPI, the consumer chooses his payment method by comparing his expected utility if he pays cash and if he pays with the EPI.

Let us start by the case in which the merchant does not accept the EPI. If the merchant sets  $p \leq v$ , the consumer wishes to buy the good by paying cash, as his surplus  $v - p$  is positive. Otherwise, he does not buy the good.

Now consider the case in which the merchant accepts the EPI. If the merchant sets  $p \leq v$ , the consumer wishes to buy the good, as he obtains at least a positive surplus if he pays cash. He decides to use the EPI if his expected utility is higher than if he pays cash. It follows that, if  $p \leq v$ , a consumer wishes to use the EPI if and only if:

$$v - p + b_B - f - \alpha_B(1 - q)xL \geq v - p,$$

that is, if and only if

$$b_B - f - \alpha_B(1 - q)xL \geq 0.$$

If the merchant sets  $p > v$ , the consumer never uses cash. The consumer buys the good and pays with the EPI if and only if

$$v - p + b_B - f - \alpha_B(1 - q)xL \geq 0.$$

We denote by  $D_B$  the probability that a consumer wishes to use the EPI. Considering consumers' heterogeneity, it follows from the previous analysis that

$$D_B = \begin{cases} 1 - H_B(f + \alpha_B(1 - q)xL) & \text{if } p \leq v \\ 1 - H_B(f + \alpha_B(1 - q)xL + p - v) & \text{if } p > v. \end{cases}$$

Note that the probability that the consumer wishes to use the EPI decreases with the transaction fee, the consumer's liability, the expected amount of fraud loss, but increases with the probability that the fraud is detected.

## 4.2 Stage 2: EPI acceptance and investments in fraud detection

### 4.2.1 Prices and card acceptance condition

We now determine the price that is chosen by each merchant, along with the decision to accept the EPI and invest in fraud detection technologies. We start by showing that, because of assumptions (A1) and (A2), the profit of a merchant who accepts the EPI is maximised when he sets a price such that cash-users are not excluded from the market. It follows that merchants who accept the EPI and merchants who do not accept the EPI choose the same price. This enables us to derive the EPI acceptance condition.

**Lemma 1** *Each monopolistic merchant maximises its profit by setting  $p^* = v$ .*

**Proof.** See Appendix B. ■

We are now able to derive the condition under which a merchant accepts the electronic payment instrument. A merchant accepts the EPI if he makes more profit by doing so, that is if

$$v - d + D_B(f + \alpha_B(1 - q)xL)(b_S - \alpha_S x(1 - q)L - m - C_S(e_S)) \geq v - d.$$

Since  $D_B(f + \alpha_B(1 - q)xL) \geq 0$ , this condition is equivalent to

$$b_S - \alpha_S x(1 - q)L - m - C_S(e_S) \geq 0. \quad (2)$$

Note that a merchant does not accept the EPI if the merchant fee is high or if the amount of the expected fraud loss is high.

### 4.2.2 Investment in fraud detection technologies

A merchant that accepts the EPI can invest in fraud detection technologies. The amount of investment in fraud detection technologies, which we denote by  $e_S^*$ , maximises the merchant's profit under the constraint that the merchant accepts the EPI.

**Lemma 2** *If the merchant fee is not too high, all merchants such that  $b_S \geq \hat{b}_S(\alpha_S, \alpha_B, x, L, m, f)$  accept the electronic payment instrument, where  $\hat{b}_S(\alpha_S, \alpha_B, x, L, m, f) \in [\underline{b}_S, \overline{b}_S]$ . The profit maximising investment for a merchant who accepts the EPI solves:*

$$\alpha_S x L \left. \frac{dq}{de_S} \right|_{e_S^*} - C'_S(e_S^*) = [b_S - \alpha_S x(1 - q)L - m - C_S(e_S^*)] \frac{\zeta_B|_{e_S^*}}{e_S^*}, \quad (3)$$

where  $\zeta_B = \frac{-dD_B/de_S}{D_B/e_S}$  denotes the elasticity of the consumer's demand to the investment effort.

**Proof.** See Appendix C. ■

The merchant chooses its fraud prevention effort so as to equalize the marginal benefits of investments in fraud detection technologies and the marginal cost of investments. The marginal benefits of investments are equal to the marginal gains from lower expected fraud losses (term  $\alpha_S x L (dq/de_S)$  in (3)), and to the marginal benefits that are due to an increase in the volume of electronic transactions (term  $[b_S - \alpha_S x (1 - q)L - m - C_S(e_S^*)] (\zeta_B|_{e_S^*}/e_S^*)$  in (3)).

Let us detail each of the two effects that will be referred to as the *expected loss effect* and the *transaction volume effect*. First, if the merchant invests in fraud detection technologies, this increases the probability that a fraudulent transaction is detected, and therefore, this reduces the amount of the expected loss that he has to bear when he accepts the EPI. The expected loss effect has a positive impact on merchant's investments. Second, if consumers bear a positive share of fraud losses, the probability that a consumer wishes to use the electronic payment instrument is impacted positively by the merchant's investments, as the expected loss decreases. The transaction volume effect has also a positive impact on merchant's investments.

Remark that, because of the transaction volume effect (if  $\alpha_B \neq 0$ ), the merchants invest in fraud prevention technologies even if they bear no liability for fraud, that is if  $\alpha_S = 0$ . In two-sided markets, the liability regime is not the only incentive that can be used to encourage merchant investment, as merchants care about the transaction volume, which is related to consumer demand. This effect is not present in the literature on law and economics that we mentioned in section 2.

Note also that merchants exert a positive externality on the payment platform and on consumers if  $\alpha_B \neq 0$ , because their investment in fraud detection technologies reduces the amount of their expected fraud loss.

If  $\alpha_B = 0$ , the zero liability rule applies for consumers. In this case, all merchants who accept the EPI invest the same amount in fraud detection technologies, which is implicitly defined by

$$\alpha_S x L \left. \frac{dq}{de_S} \right|_{e_S^*} = C'_S(e_S^*). \quad (4)$$

As investments do not impact consumer demand, the transaction volume effect is null under the zero liability rule. A merchant who obtains a higher transaction benefit does not have higher investment incentives, as the marginal benefits obtained through a higher transaction volume are equal to zero.

### 4.2.3 Comparative statics

In Lemma 3, we give some comparative statics to explain how a merchant's investment in fraud detection technologies vary with the transaction fees, the liability levels and the benefit that a merchant obtains of being paid with the electronic payment instrument.

**Lemma 3** *If  $\alpha_B > 0$ , the merchant's investments in fraud detection technologies increase with the consumer liability, the consumer transaction fee, the merchant's transactional benefit, and the merchant's liability, but they decrease with the merchant fee.*

**Proof.** See Appendix D. ■

We proved in Lemma 2 that a merchant's investments in fraud detection technologies are chosen such that the marginal benefits are equal to the marginal costs of investments. If the merchant fee increases (resp. if the merchant's transactional benefit increases), all other things being equal, the marginal benefits from investment decrease, because of a reduction of the transaction volume effect. The merchant reacts by reducing its investments in fraud detection technologies.

If the merchant's liability increases, this increases the expected loss effect, because the merchant has more to save when a fraud is detected, whereas this decreases the transaction volume effect, as the merchant's margin per transaction is reduced. Under Assumption (A2), the first effect dominates and the merchant reacts by increasing its investments in fraud detection technologies.

Moreover, if the consumer liability increases or if the consumer fee increases, this increases the transaction volume effect, because the impact of merchant's investments on consumer demand increase. Therefore, the merchant's investments increase.

If the zero liability rule applies, from (4), the merchant's investments in fraud detection technologies do not depend on the transaction fees that are chosen by the payment platform. They only depend on the merchant's liability and the expected loss. As when  $\alpha_B > 0$ , they decrease with the merchant's liability and it can be shown that they decrease with the expected fraud loss.

In Lemma 4, we determine how the transaction fees and the liability levels impact the probability that a merchant accepts the electronic payment instrument.

**Lemma 4** *The probability that a merchant accepts the EPI decreases with the merchant fee, with the consumer fee and with the level of liability that is borne by merchants.*

**Proof.** See Appendix E. ■

A higher merchant fee lowers the transaction margin that the merchant obtains if he accepts the EPI, whereas it reduces the merchant's incentives to accept the EPI, which is a standard effect in the literature on payment cards. Moreover, in our model, the probability that a merchant accepts the EPI also depends on the consumer fee, because merchants exert a positive externality on consumers when they choose to invest in fraud detection technologies. Indeed, this interaction, which is novel in the literature on payment platforms, arises when  $\alpha_B \neq 0$  and this is specific to our model setting. Finally, a higher consumer fee decreases the probability that a consumer wishes to use the EPI, which reduces the marginal benefits of investing in fraud detection technologies and the benefits of accepting the EPI for the merchant. Therefore, the probability that a merchant accepts the EPI decreases with the consumer fee.

Most importantly, our model is the first to highlight the impact of liability regimes on merchants' acceptance of payment media. We show in Appendix E that the level of liability has an ambiguous impact on merchants' choice to accept the electronic payment instrument. On the one hand, a higher liability level increases the loss in case of a fraudulent use of the EPI, which discourages merchants to accept the EPI. On the other hand, it increases the level of effort made by merchants, which reduces the probability that the EPI is fraudulently used - and thus increases the probability that a consumer wishes to use the EPI. From assumption (A2), the first effect dominates in our framework, and therefore, the probability that a merchant accepts the EPI decreases with his liability level.

### 4.3 Stage 1: Prices and liability levels

At the first stage, the payment platform chooses the prices that maximise its profit,

$$\pi_P = (f + m - c)V_P - EL_P,$$

where  $V_P$  denotes the transaction volume, as follows:

$$V_P = \int_{\widehat{b_S}}^{\overline{b_S}} h(b_S)(1 - H_B(f + \alpha_B x L(1 - q^*)))db_S, \quad (5)$$

$EL_P$  denotes the average expected loss, or:

$$EL_P = \alpha_P x L \int_{\widehat{b_S}}^{\overline{b_S}} (1 - q^*)h(b_S)(1 - H_B(f + \alpha_B x L(1 - q^*)))db_S, \quad (6)$$

and

$$q^* = q(e_S^*).$$



If  $\alpha_B = 0$ , as  $q^*$  does not depend on  $b_S$ , we have

$$EL_P = \alpha_P x L (1 - q^*) V_P. \quad (7)$$

Note that, for all  $\alpha_B \in [0, 1]$ , the transaction volume decreases with the consumer transaction fee and with the merchant fee. While this effect is standard in the literature, another question arises in our framework, that is the impact of the transaction prices and the merchants' liability on the expected fraud loss that is borne by the payment platform.

#### 4.3.1 Variations of the expected loss with the prices

We start by determining how the expected fraud loss is impacted by the choice of transaction fees and by the level of liability that is borne by merchants.

**Proposition 1** *The expected loss incurred by the payment platform on fraudulent transactions ( $EL_P$ ) decreases with the consumer transaction fee and with the level of liability that is borne by merchants.  $EL_P$  decreases with the merchant fee only if the elasticity of the merchant's effort to the merchant fee is small or if the elasticity of the merchant's demand to the merchant fee is high.*

**Proof.** See Appendix F. ■

An increase in the consumer fee decreases the number of merchants who accept the EPI, whereas it increases merchants' investments in fraud detection technologies. It follows that a higher consumer fee decreases the expected loss that is incurred by the payment platform.

Moreover, a higher level of liability for merchants decreases the expected loss that is borne by the payment platform, as it decreases merchants' acceptance of the EPI, whereas it increases merchants' investment in fraud detection technologies.

An increase in the merchant fee has two effects on the expected loss that is incurred by the payment platform. The higher the merchant fee, the lower the number of merchants who accept the EPI, and the lower the transaction volume. This effect reduces the expected loss that is incurred by the payment platform. At the same time, a higher merchant fee decreases the merchants' investment in fraud detection technologies, which increases the expected loss that is borne by the payment platform. The impact of an increase in the merchant fee on the expected loss depends on how both effects compensate each other.

#### 4.3.2 The profit maximising price structure

Proposition 2 gives the profit maximising price structure for a given level of merchants' liability.

**Proposition 2** *The profit maximising price structure reflects the platform's trade-off between balancing profits between both sides of the market and minimizing the expected loss on fraudulent transactions. The total price is implicitly defined by*

$$\frac{f + m - c}{f} = \frac{1}{\varepsilon_B^V(f)} + \frac{\partial EL_P / \partial f}{f \partial V_P / \partial f},$$

and the price structure verifies

$$\frac{f}{m} = \frac{\frac{1}{\varepsilon_S^V(m)} + \frac{\partial EL_P / \partial m}{m \partial V_P / \partial m}}{\frac{1}{\varepsilon_B^V(f)} + \frac{\partial EL_P / \partial f}{f \partial V_P / \partial f}},$$

where  $\varepsilon_B^V(f) = -(\partial V_P / \partial f)(f / V_P)$  and  $\varepsilon_S^V(m) = -(\partial V_P / \partial m)(m / V_P)$  denote the elasticity of the transaction volume to the consumer fee and the merchant fee respectively.

**Proof.** We denote by  $M_P = f + m - c$  the payment platform's gross margin. Assume that there is an interior solution. Solving for the first-order conditions of profit maximisation yields

$$\frac{\partial \pi_P}{\partial f} = M_P \frac{\partial V_P}{\partial f} + V_P - \frac{\partial EL_P}{\partial f} = 0,$$

and

$$\frac{\partial \pi_P}{\partial m} = M_P \frac{\partial V_P}{\partial m} + V_P - \frac{\partial EL_P}{\partial m} = 0.$$

These equations can be rewritten as

$$\frac{f + m - c}{f} = \frac{-V_P}{f \partial V_P / \partial f} + \frac{\partial EL_P / \partial f}{f \partial V / \partial f}, \quad (8)$$

and

$$\frac{f + m - c}{m} = \frac{-V_P}{m \partial V_P / \partial m} + \frac{\partial EL_P / \partial m}{m \partial V_P / \partial m}. \quad (9)$$

Introducing the elasticities  $\varepsilon_B^V(f) = -(\partial V_P / \partial f)(f / V_P)$  and  $\varepsilon_S^V(m) = -(\partial V_P / \partial m)(m / V_P)$  and dividing the first equation by the second equation yields the result of Proposition 2.

In Appendix G-A, we show that the second-order conditions of profit maximisation are verified if  $\alpha_B = 0$ . ■

It is interesting to compare the prices that we find in an interior solution with the prices obtained in the standard two-sided market monopoly pricing formula obtained by Rochet and Tirole (2003). Equations (8) and (9) show that with respect to the standard price structure in two-sided markets, the price structure that we obtain encompasses an additional term that takes into account the platform's trade-off between maximising its profit and minimizing the

expected loss on fraudulent transactions.

Notice that if the zero liability rule applies for consumers (that is if  $\alpha_B = 0$ ), from (7), the expected loss only depends on the transaction prices through the transaction volume. It follows that, in this case, the price structure is the same as the one obtained by Rochet and Tirole (2003), that is:

$$\frac{f}{m} = \frac{\varepsilon_B^V(f)}{\varepsilon_S^V(m)},$$

and the total price is implicitly defined by:

$$\frac{f + m - c - (1 - \alpha_S)xL(1 - q^*)}{f} = \frac{1}{\varepsilon_B^V(f)}.$$

For instance, if  $\alpha_B = 0$ , with uniform distribution on  $[0, 1]$  for  $b_B$  and  $b_S$ , with a cost function  $C_S(e_S) = k(e_S)^2/2$ , with  $q(e_S) = \gamma e_S$  and  $c = 0$ , we prove in Appendix H that the profit maximising transaction fees are

$$m = \frac{1 + xL(1 - 3\alpha_S) + \frac{(xL\gamma)^2}{k}(2\alpha_S^2 - \alpha_S)}{3}, \quad (10)$$

and

$$f = \frac{1 + xL + \frac{(\alpha_S^2 - 2\alpha_S)(xL\gamma)^2}{2k}}{3}.$$

Note that the consumer fee is higher than the merchant fee if  $\alpha_S \neq 0$ , as we have

$$f - m = \alpha_S xL \left[ 1 - q^* + \alpha_S \frac{xL\gamma^2}{2k} \right] \geq 0. \quad (11)$$

If the demands are uniform and symmetric, in the standard case of the literature on payment cards, the profit maximising transaction fees are such that  $f = m$ . Equation (11) shows that, if  $\alpha_S > 0$ , the payment platform tends to lower the merchant fee to provide merchants with incentives to invest in fraud detection technologies. The price structure changes in favor of merchants. This is not necessarily the case if demands are not symmetric, or if  $\alpha_B \neq 0$ . If  $\alpha_B \neq 0$ , the payment platform can use the transaction prices on both sides of the market to encourage merchants to invest in fraud detection technologies, because of the transaction volume effect that we highlighted in Lemma 2.

### 4.3.3 The profit maximising level of liability

We have assumed that the payment platform has the opportunity to choose the merchant's level of liability at the same stage as the transaction prices. Thus, we start by determining how the merchant's level of liability impacts the platform's profit. We know from Proposition 1 that the expected loss that is borne by the payment platform decreases with the level of liability borne by merchants. It remains to study how the level of liability borne by merchants impacts the transaction volume. We have

$$\frac{\partial V_P}{\partial \alpha_S} = \underbrace{\frac{-\partial \widehat{b}_S}{\partial \alpha_S} h_S(\widehat{b}_S)(1 - H_B(f + \alpha_B x L(1 - q^*)))}_{\text{Term I}} + \underbrace{\int_{\widehat{b}_S}^{\overline{b}_S} h_S(b_S) \frac{\partial D_B(f + \alpha_B x L(1 - q^*))}{\partial \alpha_S} db_S}_{\text{Term II}}. \quad (12)$$

The first term of (12) is negative. It reflects the fact that fewer merchants accept the EPI when the level of liability that is borne by merchants increases. The second term of (12) is positive. It shows that more consumers wish to pay with the EPI when merchants invest in fraud detection technologies. It follows that a higher level of liability for merchants has an ambiguous impact on the transaction volume. Note that if the elasticity of the merchants' demand to their liability level is small (that is, if term I is small), the transaction volume may increase with the merchants' level of liability. Moreover, if the zero liability rule applies for consumers, the second term of (12) is null, and the transaction volume decreases with the merchant's level of liability. Proposition 3 gives the profit maximising level of liability for merchants.

**Proposition 3** *A monopolistic payment platform chooses a level of liability for merchants that reflects a trade-off between minimizing the expected loss on fraudulent transactions and maximising the transaction volume. The interior solution for the profit maximising level of liability for merchants solves*

$$(f + m - c) \frac{\partial V_P}{\partial \alpha_S} = \frac{\partial EL_P}{\partial \alpha_S}.$$

*If the transaction volume increases with the liability level that is borne by merchants, there is a corner solution such that the payment platform lets the merchants bear all the losses.*

**Proof.** The payment platform chooses the level of liability that maximises its profit. Solving for the first-order condition of profit maximisation yields

$$\frac{\partial \pi_P}{\partial \alpha_S} = (f + m - c) \frac{\partial V_P}{\partial \alpha_S} - \frac{\partial EL_P}{\partial \alpha_S}.$$

In an interior solution, we have

$$(f + m - c) \frac{\partial V_P}{\partial \alpha_S} = \frac{\partial EL_P}{\partial \alpha_S}.$$

From Proposition 1, we know that the expected loss decreases with the level of liability that is borne by the merchants. It follows that, if the transaction volume increases with the level of liability borne by merchants, the profit maximising liability level is a corner solution, with the merchants bearing the maximum share of the loss.

In Appendix G-B, we show that the second-order conditions of profit maximisation are verified if  $\alpha_B = 0$ . ■

Proposition 3 shows that the payment platform has an incentive to share the losses on fraudulent transactions with the merchants, as this encourages merchants to accept the electronic payment instrument, unless merchants' demand is inelastic to the level of liability. However, the choice of a liability regime is also a means for the payment platform to extract rents from merchants if the elasticity of the merchants' demand to the liability level is small.

In Appendix H, we prove that, if  $\alpha_B = 0$ , with uniform distribution on  $[0, 1]$  for  $b_B$  and  $b_S$ , with a cost function  $C_S(e_S) = k(e_S)^2/2$ , and a detection probability  $q(e_S) = \gamma e_S$ , the profit maximising level of liability for merchants is equal to 1. This result is not general under the zero liability rule. In other cases, the liability for fraud is shared between the platform and the merchants.<sup>19</sup>

## 5 Welfare maximising liability levels

To study welfare maximizing liability levels, we assume that the merchant's level of liability is decided by a social planner at the first stage, who maximises the sum of the platform's profit, the consumer surplus and the merchant surplus. Then, the payment platform chooses the transaction fees at the following stage. Our aim is to compare the profit maximising level of liability for merchants, which is chosen by the payment platform, to the welfare maximising level of liability for merchants. We start by analyzing the simple case in which consumers bear zero liability on fraudulent transactions.<sup>20</sup>

For this purpose, we need to determine how the liability level that is borne by merchants impacts the transaction fees that are chosen by the payment platform.

<sup>19</sup> A general result under the zero liability rule is that the payment platform chooses the level of liability for merchants that maximises the probability of fraud detection (See Appendix G-B).

<sup>20</sup> In the future, our analysis will be extended to the case in which consumers bear some responsibility for fraud.

**Lemma 5** *If the zero liability rule applies for consumers, the transaction fees chosen by the payment platform decrease with the level of liability that is borne by merchants.*

**Proof.** See Appendix I-A and I-B. ■

When the level of liability that is borne by merchants increases, this has two effects on the payment platform's profit. First, this reduces the share of the expected loss that is borne by the payment platform, which amounts to a reduction of its marginal cost. The payment platform may decide to pass through this marginal cost reduction to the users by reducing the transaction fees. Second, merchants invest more in fraud prevention technologies, which reduces the amount of the expected loss that is borne by the payment platform for each transaction. This effect can be reinforced if the payment platform decides to reduce the transaction fees paid by the users, as this increases the transaction volume. Therefore, if the level of liability that is borne by merchants increases, the payment platform has an incentive to lower the transaction fees on both sides of the market. The payment platform loses some rents from the transaction fees, but this loss is compensated by higher rent extraction through the liability regime, which encourages merchant investment.

We are now able to compare the profit maximising level of liability and the welfare maximising level of liability for merchants if consumers do not bear any liability for fraudulent transactions. We assume that social welfare is a concave function of the transaction fees.<sup>21</sup>

**Proposition 4** *Under the zero liability rule for consumers, if social welfare is a concave function of  $\alpha_S$ , the profit maximising level of liability for merchants is lower than (or equal to) the welfare maximising level of liability.*

**Proof.** See Appendix J-B. ■

We showed in Proposition 5 that the transaction fees paid by the users decrease with the level of liability that is borne by merchants. A direct consequence of Proposition 5 is that consumer and merchant surplus increase when merchants' liability increase. It follows that, from the point of view of total user surplus maximisation, it is socially optimal to let the merchants bear the maximum liability on fraudulent transactions. However, if the regulator takes into account the payment platform's profit, the welfare maximising level of liability for merchants is not necessarily equal to one.

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<sup>21</sup>  $W$  is concave in  $\alpha_S$  for instance if  $b_S$  and  $b_B$  are uniformly distributed on  $[0, 1]$  under some assumptions about the cost of fraud prevention and the sensitivity of the detection probability which are precised in Appendix J. In general, it is possible to prove that  $\pi_P$  is concave in  $\alpha_S$ , however, the total user surplus is not necessarily concave in  $\alpha_S$ .



The payment platform does not place enough liability on merchants to maximise social welfare, except in the case where it is maximises its profit by letting the merchants bear the maximum liability on fraudulent transactions. This is because the payment platform internalizes imperfectly the impact of the liability regimes on consumer and merchant surplus. Note that this result is driven by the assumption that the probability to detect a fraudulent transaction only depends on merchants' investment. The result could change if the investments were shared by the payment platform and by the merchants.

## 6 The role of interchange fees

In this section, we examine an important regulatory challenge, which is the impact of merchant liability on the level of interchange fees.<sup>22</sup> This issue has been examined in the United-States after the vote of the Dodd-Frank act in July 2010, which gives to the Federal Reserve Board the power to regulate interchange fees on debit card transactions. Among the regulatory rules, the "fraud adjustment rulemaking" provides the Board with the opportunity to assess how card networks' authorization choices and fraud procedures may burden the merchant community and potentially increase the volume of debit card fraud. The rulemaking also gives the Board the opportunity to promote the use of the fraud adjustment mechanism as a means of creating incentives for banks and merchants to migrate to more effective fraud detection technologies.

To study this issue, we modify our model setting, by making the standard assumption that the payment platform is now composed of imperfectly competitive issuers and perfectly competitive acquirers.<sup>23</sup> We also assume for simplicity of the model that consumers bear no liability on fraudulent transactions ( $\alpha_B = 0$ ). The issuers charge a fee  $f^*(c_I - a)$  to the consumers, whereas the acquirers charge merchants with their perceived marginal cost, that is  $m^* = a + c_A$ . As in the literature, we make the standard assumption that  $f^*$  is decreasing with  $a$ , and that the pass-through rate is lower than one, that is  $\partial f^*/\partial a \leq 1$ . At the first stage of the game, the payment platform chooses the level of interchange fee that maximises banks' joint profit. Then banks choose the transaction prices, merchants invest in fraud detection technologies and consumers make their payments decisions. We denote the profit maximising interchange fee by  $a^P$ , and study how the profit maximising interchange fee is impacted by the level of liability that is borne by merchants.

**Proposition 5** *If the issuers are imperfectly competitive and if the acquirers are perfectly competitive, the profit maximising interchange fee decreases with the level of liability that is borne*

<sup>22</sup> Interchange fees are paid by the acquiring bank to the issuing bank each time a consumer makes a transaction.

<sup>23</sup> For instance, this assumption is also made in Rochet and Tirole (2002).

*by merchants.*

**Proof.** See Appendix K. ■

Proposition 4 has important implications for regulatory decisions about interchange fees. It means that, if merchants bear a higher share of the loss on fraudulent transactions, the profit maximising interchange fee becomes lower. The result of Proposition 4 may change if consumers are held liable for fraudulent transactions. In this case, merchants' investments are impacted by the transaction fees and by the interchange fee that is chosen by the payment platform. The payment platform may decide either to lower or to increase the interchange fee to provide merchants with incentives to increase their investment in fraud detection technologies, depending on the relative importance of the expected loss effect and the transaction volume effect that we highlighted in Lemma 2.

Another interesting aspect of the problem is that regulators may wish to fix a maximum level for the interchange fee, but the payment platform can react by adjusting the level of liability that is borne by merchants for fraudulent transactions. In Appendix K, we show in a simple example that, if the regulator chooses a low level for the interchange fee, the payment platform reacts by choosing a high level of liability for merchants, which may not be desirable from the point of view of social welfare.

## 7 Platform's investments

We analyze if our welfare result holds in an extension of the model that allows the payment platform to invest. In a supplementary note, that is available upon author's request, we show that the welfare result obtained under the zero liability rule does not hold.<sup>24</sup> This is because the prices chosen by the payment platform do not necessarily decrease with the level of liability borne by merchants. The intuition of this result is the following. A higher level of liability for merchants has three effects on the platform's incentives to invest in fraud detection technologies. First, it lowers the transaction volume, which lowers the platform's investments. Second, it decreases the losses that are due to fraudulent transactions. This effect also lowers the platform's incentives to invest in fraud detection technologies. Finally, a higher level of liability for merchants increases merchants' investments. If the platform's investments and the merchants' investments reinforce each other, the platform has higher incentives to invest in fraud detection technologies. Therefore, the platform trades-off between lowering the merchant fee to encourage

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<sup>24</sup> Except in the case where the platform's cost function is linear and if the detection probability is linear in the platform's investment effort.

merchants' investments and increasing the merchant fee to cover its investments costs. In this case, the detection probability does not always increase with the level of liability that is borne by merchants, since a higher liability for merchants may decrease the platform's investments incentives.

## 8 Conclusion and discussion

Our results highlight the fact that liability regimes can be used by monopolistic payment platforms to extract rents from merchants. From the point of view of a social planner, payment platforms do not place enough liability on merchants for investments that only depend on the merchants' side under the zero liability rule. This result changes if the platform shares the cost of investments with merchants.

Another issue that deserves further research is the problem of compliance in payment systems. This paper has considered only prices and liability regimes as an incentive to encourage merchant investment. However, we think that it would be interesting to compare the impact of different measures on investments and fraud losses such as compliance rules, price incentives and liability shifts.

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## 10 Appendix

**Appendix A: Consumer Protection Laws in Various Countries.** The following table provides some examples of consumer protection laws in various countries. The common feature of consumer protection laws is that consumer bear hardly meaningful responsibility for fraudulent use of cards in all countries.

Country	Name of the Law	Consumer Protection
USA	TILA/Reg Z for credit cards	Capped at \$50 for all unauthorized transactions.
	Debit Cards	If the cardholder fails to notify the card issuer within 2 days, the cardholder's maximum liability is \$500, of which only \$50 can be attributed to fraud occurring during the first 2 days after the cardholder learnt the loss or theft.
Europe	Payment Service Directive	The cardholder has 13 months to contest an unauthorized transaction. The cardholder's liability is capped at 150 euros if he has failed to keep the personalized security measures safe.  If the cardholder was a victim from an identity theft, he cannot be held liable. No liability in all cases after the fraud is reported. Right for payment service users to enjoy immediate refund of unauthorized transactions following the establishment of the proof.

**Appendix B: Proof of Lemma 1.** We prove in Lemma 1 than the merchants who accept the EPI and the merchants who do not accept the EPI set the same price  $p^* = v$ . There are

two cases: either a merchant refuses the EPI or he accepts it. Let us start by the first case. If a merchant refuses the EPI, all consumers pay cash, and he makes profit<sup>25</sup>

$$\pi = p - d.$$

In this case, the merchant's profit is maximised when he sets  $p = v$ , and we have that

$$\pi = v - d.$$

In the second case, the merchant accepts the EPI. If he sets  $p \leq v$ , he attracts both EPI and cash users. In this case, he makes profit

$$\pi = p - d + D_B(f + \alpha_B(1 - q)xL)(b_S - \alpha_S x(1 - q)L - m - C_S(e_S)).$$

This profit is maximised at  $p^* = v$ .

If he sets  $p > v$ , the merchant attracts only EPI users. In this case, he makes profit

$$\pi = (p - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S))D_B(f + p - v + \alpha_B(1 - q)xL). \quad (13)$$

We now show that the merchant always makes more profit by setting  $p^* = v$ . For this purpose, we prove that

$$\lim_{p \rightarrow v} \frac{d\pi}{dp} < 0,$$

and that for any  $p > v$ , we have

$$\frac{d\pi}{dp} < 0.$$

From (13), we have:

$$\frac{d\pi}{dp} = D_B(f + p - v + \alpha_B(1 - q)xL) - h_B(f + p - v + \alpha_B(1 - q)xL)(p - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S)).$$

We also have

$$\lim_{p \rightarrow v} \frac{d\pi}{dp} = D_B(f + \alpha_B(1 - q)xL) - h_B(f + \alpha_B(1 - q)xL)(v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S)).$$

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<sup>25</sup>Our results would not change if we added a parameter  $q_0$  to model the probability that the merchant is paid with counterfeit notes and coins. [FOR US: In this case, we would only have to modify assumption (A2)

$v - d - q_0 v \geq \frac{h_B(f + \alpha_B(1 - q)xL)}{1 - H_B(f + \alpha_B(1 - q)xL)}]$



This quantity is negative if and only if

$$v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S) \geq \frac{1 - H_B(f + \alpha_B(1 - q)xL)}{h_B(f + \alpha_B(1 - q)xL)}. \quad (14)$$

As the merchant accepts the EPI, we have that  $b_S - \alpha_S x(1 - q)L - m - C_S(e_S) \geq 0$ . It follows that (A2) is a sufficient condition for (14) to hold.

We can now prove that for any  $p > v$ ,  $\frac{d\pi}{dp} < 0$ . To simplify the notations, we denote by  $\widetilde{D}_B = D_B(f + p - v + \alpha_B(1 - q)xL)$ . We have

$$\begin{aligned} \frac{d\pi}{dp} &= \widetilde{D}_B - h_B(f + p - v + \alpha_B(1 - q)xL)(p - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S)) \\ &< \widetilde{D}_B - h_B(f + p - v + \alpha_B(1 - q)xL)(v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S)) \\ &= \widetilde{D}_B \left[ 1 - \frac{h_B(f + p - v + \alpha_B(1 - q)xL)}{1 - H_B(f + p - v + \alpha_B(1 - q)xL)}(v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S)) \right]. \end{aligned}$$

We have  $\widetilde{D}_B \geq 0$ . Therefore, a sufficient condition for  $\frac{d\pi}{dp} < 0$  to hold is that the term into bracket is negative. The term into brackets is negative if and only if

$$v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S) \geq \frac{1 - H_B(f + p - v + \alpha_B(1 - q)xL)}{h_B(f + p - v + \alpha_B(1 - q)xL)}.$$

As by assumption (A1) the hazard rate is increasing, we have that, for any  $p > v$ ,

$$\frac{1 - H_B(f + p - v + \alpha_B(1 - q)xL)}{h_B(f + p - v + \alpha_B(1 - q)xL)} \leq \frac{1 - H_B(f + \alpha_B(1 - q)xL)}{h_B(f + \alpha_B(1 - q)xL)}.$$

From assumption (A2), we have that

$$v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S) \geq \frac{1 - H_B(f + \alpha_B(1 - q)xL)}{h_B(f + \alpha_B(1 - q)xL)}.$$

It follows that

$$v - d + b_S - \alpha_S x(1 - q)L - m - C_S(e_S) \geq \frac{1 - H_B(f + p - v + \alpha_B(1 - q)xL)}{h_B(f + p - v + \alpha_B(1 - q)xL)}.$$

Therefore, we have that, for any  $p > v$ ,  $\frac{d\pi}{dp} < 0$ . It follows that the merchant makes more profit by setting  $p^* = v$ , which enables him to attract cash-users and EPI users. We can conclude that all merchants choose a price such that  $p^* = v$ .

**Appendix C: proof of Lemma 2.** We proceed in two steps. First, we determine the profit maximising level of investment of a merchant who accepts the EPI. Second, we prove that, if

the merchant fee is not too high, some merchants accept the EPI. We start by the first step. A merchant who accepts the EPI chooses the level of investment in fraud detection technologies that maximises its profit,

$$\pi = p - d + D_B(f + \alpha_B(1 - q)xL)(b_S - \alpha_S x(1 - q)L - m - C_S(e_S)).$$

Solving for the first-order condition of profit-maximisation yields

$$\left[ \alpha_S xL \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right] D_B + [b_S - \alpha_S x(1 - q)L - m - C_S(e_S^*)] \frac{dD_B}{de_S} \Big|_{e_S^*} = 0. \quad (15)$$

We define  $\zeta_B = \frac{-dD_B/de_S}{D_B/e_S}$  the elasticity of the consumers' demand to the fraud detection technology. The merchant's investment in fraud detection technologies is implicitly defined by

$$\alpha_S xL \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) = [b_S - \alpha_S x(1 - q)L - m - C_S(e_S^*)] \frac{\zeta_B|_{e_S^*}}{e_S^*}.$$

The second-order condition must be verified at  $e_S^*$ , that is,

$$\left[ -C''_S(e_S^*) + \alpha_S xL \frac{d^2q}{d^2e_S} \Big|_{e_S^*} \right] D_B + 2 \left[ \alpha_S xL \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right] \frac{dD_B}{de_S} \Big|_{e_S^*} + M_S \frac{d^2D_B}{d^2e_S} \Big|_{e_S^*} \leq 0, \quad (16)$$

where  $M_S = b_S - \alpha_S x(1 - q)L - m - C_S(e_S^*)$ .

Under the assumption that  $C_S$  is convex and  $q$  is concave, the first term of this inequality is negative. To determine the sign of the second term, we use equation (15). Since  $\zeta_B|_{e_S^*}$  is negative and since the merchant's margin is positive if he accepts the EPI, we conclude that  $\alpha_S xL \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \leq 0$  at the profit maximising level of investment. We have

$$\frac{\partial D_B}{\partial e_S} = h_B(\alpha_B xL(1 - q^*) + f)\alpha_B xL \frac{dq}{de_S}, \quad (17)$$

and

$$\frac{\partial^2 D_B}{\partial e_S^2} = -h'_B(\alpha_B xL(1 - q^*) + f)(\alpha_B xL \frac{dq}{de_S})^2 + h_B(\alpha_B xL(1 - q^*) + f)\alpha_B xL \frac{d^2q}{de_S^2}. \quad (18)$$

From (17), we have  $\frac{dD_B}{de_S} \Big|_{e_S^*} \geq 0$ . It follows that the second term of (16) is negative. Finally, since  $M_S \geq 0$  and since  $\frac{d^2D_B}{d^2e_S} \Big|_{e_S^*} \leq 0$  from (18), the last term of (16) is negative. It follows that the second-order condition is always verified at  $e_S^*$ .

We now show that merchants accept the EPI if their transactional benefit  $b_S$  is such that  $b_S \geq \widehat{b}_S(\alpha_S, \alpha_B, x, L, m, f)$ , which is the second step of our proof. A merchant accepts the EPI if and only if

$$b_S - m - \alpha_S x(1 - q)L - C_S(e_S^*) \geq 0. \quad (19)$$

Let us consider the function  $M_S(y) = y - \alpha_S x(1 - q)L - C_S(e_S^*)$ , where  $y = b_S - m$ . Note that (19) does not hold if  $y < 0$ , which happens if the merchant fee is too high. We have that

$$M'_S(y) = 1 + \frac{de_S}{dy} \Big|_{e_S^*} \left( \alpha_S x L \frac{dq}{de_S} \Big|_{e_S^*} - C'(e_S^*) \right).$$

From (15), we have that  $\alpha_S x L \frac{dq}{de_S} \Big|_{e_S^*} - C'(e_S^*) \geq 0$ . We can also prove, using (15) and the envelop theorem that  $\frac{de_S}{dy} \Big|_{e_S^*} \geq 0$ . It follows that  $M_S$  is increasing in  $y$  for all  $y \geq 0$ . Note that  $M_S(0) \leq 0$  and that the sign of  $M_S(\bar{y})$ , where  $\bar{y} = \bar{b}_S - m$ , depends on  $m$ . There are three cases.

Let us start by the first case, in which the merchant fee  $m$  is sufficiently high, such that  $M_S(\bar{y}) < 0$ . As  $M_S$  is increasing in  $y$ , for all  $b_S \in [\underline{b}_S, \bar{b}_S]$  and for all  $y = b_S - m$ , we have  $M_S(y) < 0$ . It follows that no merchant accepts the EPI.

In the second case, the merchant fee  $m$  is sufficiently low, such that  $\underline{b}_S - m > 0$  and  $M_S(\underline{y}) \geq 0$ , where  $\underline{y} = \underline{b}_S - m$ . As  $M_S$  is increasing in  $y$ , for all  $b_S \in [\underline{b}_S, \bar{b}_S]$  and for all  $y = b_S - m$ , we have  $M_S(y) \geq 0$ . It follows that all merchants accept the EPI.

In the third case, the merchant fee is such that  $M_S(\bar{y}) > 0$  and  $M_S(\underline{y}) < 0$ . As  $M_S$  is increasing in  $y$ , from the bijection theorem, there exists a threshold that we denote by  $\widehat{b}_S(\alpha_S, \alpha_B, x, L, m, f)$  such that merchants accept the EPI for all  $b_S \geq \widehat{b}_S(\alpha_S, \alpha_B, x, L, m, f)$ .

**Appendix D: proof of Lemma 3.** From the envelop theorem, we have that, for any  $z \in \{\alpha_B, \alpha_S, f, m, b_S\}$

$$\frac{\partial e_S^*}{\partial z} = - \left( \frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*} \right)^{-1} \left( \frac{\partial^2 \pi}{\partial e_S \partial z} \Big|_{e_S^*} \right).$$

As from the second-order condition  $\partial^2 \pi / \partial^2 e_S \leq 0$ , it follows that  $\partial e_S^* / \partial z$  has the same sign as  $\frac{\partial^2 \pi}{\partial e_S \partial z} \Big|_{e_S^*}$ .

Let us study the variation of the merchant's investments with the merchant fee. We have that

$$\frac{\partial^2 \pi}{\partial e_S \partial m} = -h_B(f + \alpha_B(1 - q)xL)\alpha_B x L \frac{dq}{de_S} \leq 0.$$

From the envelop theorem,  $\partial e_S^* / \partial m$  has the same sign as  $\partial^2 \pi / \partial e_S \partial m$ . It follows that the

merchant's investment always decreases with the merchant fee. Similarly, we have that

$$\frac{\partial^2 \pi}{\partial e_S \partial b_S} = h_B(f + \alpha_B(1 - q)xL)\alpha_B xL \frac{dq}{de_S} \geq 0. \quad (20)$$

It follows that the merchant's investments in fraud detection technologies increase with the merchant's transactional benefit.

We now study the variation of the merchant's investments with the consumer transaction fee. Using the same reasoning, we know that  $\partial e_S^*/\partial f$  has the same sign as  $\partial^2 \pi / \partial e_S \partial f$ . We have

$$\frac{\partial^2 \pi}{\partial e_S \partial f} = \left[ \alpha_S xL \frac{dq}{de_S} - C'_S(e_S^*) \right] \frac{dD_B}{df} + [b_S - \alpha_S x(1 - q)L - m - C_S(e_S^*)] \alpha_B xL \frac{dq}{de_S} \Big|_{e_S^*} h'_B(f + \alpha_B(1 - q)xL).$$

From the first-order condition, we have that  $\left[ \alpha_S xL \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right] \leq 0$ . We also have  $dD_B/df \leq 0$ . It follows that  $\partial^2 \pi / \partial e_S \partial f \geq 0$  since  $h'_B$  is positive. We can conclude that the merchant's investment increases with the transaction fee that is paid by the consumer.

We determine the variation of the merchant's investments with the consumer liability. Using the same reasoning,  $\partial e_S^*/\partial \alpha_B$  has the same sign as  $\partial^2 \pi / \partial e_S \partial \alpha_B$ . We have

$$\frac{\partial^2 \pi}{\partial e_S \partial \alpha_B} = \left[ \alpha_S xL \frac{dq}{de_S} - C'_S(e_S^*) \right] \frac{dD_B}{d\alpha_B} + [b_S - \alpha_S x(1 - q)L - m - C_S(e_S^*)] \alpha_B(1 - q)x^2L^2 \frac{dq}{de_S} \Big|_{e_S^*} h'_B.$$

Exactly like in the previous proof, we have that  $\partial^2 \pi / \partial e_S \partial \alpha_B \geq 0$  since  $h'_B$  is positive. It follows that the merchant's investment increases with the consumer liability.

Let us study the variation of the merchant's investments with his level of liability. From the reasoning above,  $\partial e_S^*/\partial \alpha_S$  has the same sign as  $\partial^2 \pi / \partial e_S \partial \alpha_S$ . We have that

$$\begin{aligned} \frac{\partial^2 \pi}{\partial e_S \partial \alpha_S} \Big|_{e_S^*} &= xL \frac{dq}{de_S} \Big|_{e_S^*} D_B|_{e_S^*} - x^2L^2\alpha_B(1 - q(e_S^*)) \frac{dq}{de_S} \Big|_{e_S^*} h_B(f + \alpha_B(1 - q(e_S^*))xL) \\ &= xL D_B|_{e_S^*} \frac{dq}{de_S} \Big|_{e_S^*} \left[ 1 - xL\alpha_B(1 - q(e_S^*)) \frac{h_B(f + \alpha_B(1 - q(e_S^*))xL)}{D_B|_{e_S^*}} \right]. \end{aligned}$$

From assumption (A2), we have that

$$\frac{h_B(f + \alpha_B(1 - q(e_S^*))xL)}{D_B|_{e_S^*}} \leq \frac{1}{xL\alpha_B}.$$

As  $1 - q(e_S^*) \in [0, 1]$ , it follows that

$$\frac{h_B(f + \alpha_B(1 - q(e_S^*))xL)}{D_B|_{e_S^*}} \leq \frac{1}{xL\alpha_B(1 - q(e_S^*))}.$$

Therefore, we have that

$$1 - xL\alpha_B(1 - q(e_S^*)) \frac{h_B(f + \alpha_B(1 - q(e_S^*))xL)}{D_B|_{e_S^*}} \geq 0.$$

As  $\left. \frac{dq}{de_S} \right|_{e_S^*} \geq 0$  and  $xL D_B|_{e_S^*} \geq 0$ , we can conclude that

$$\left. \frac{\partial^2 \pi}{\partial e_S \partial \alpha_S} \right|_{e_S^*} \geq 0.$$

It follows that, from assumption (A2), the merchant's investments in fraud detection technologies increase with his liability level.

#### Appendix E: Proof of Lemma 4.

**Impact of the level of liability borne by merchants on EPI acceptance:** From (2), the threshold above which merchants accept the EPI solves

$$\widehat{b}_S - m - \alpha_S xL(1 - q^*) - C_S(e_S^*) = 0.$$

Differentiating this equation with respect to  $\alpha_S$ , we obtain that

$$\frac{\partial \widehat{b}_S}{\partial \alpha_S} \left[ 1 + \left( \alpha_S xL \left. \frac{dq^*}{de_S} \right|_{e_S^*} - C'_S(e_S^*) \right) \frac{de_S^*}{db_S} \right] = xL(1 - q^*) + \frac{de_S^*}{d\alpha_S} \left( C'_S(e_S^*) - \alpha_S xL \left. \frac{dq^*}{de_S} \right|_{e_S^*} \right). \quad (\text{E-1})$$

From (15), we have that  $C'_S(e_S^*) - \alpha_S xL \left. \frac{dq^*}{de_S} \right|_{e_S^*} \geq 0$ . From Lemma 3, we know that  $de_S^*/d\alpha_S \geq 0$ .

It follows that the right-hand side of the equality is positive.

Let us now determine the sign of the left-hand side of the equality. From Lemma 3, we know that

$$\frac{de_S^*}{db_S} = - \left( \left. \frac{\partial^2 \pi}{\partial^2 e_S} \right|_{e_S^*} \right)^{-1} \left( \left. \frac{\partial^2 \pi}{\partial e_S \partial b_S} \right|_{e_S^*} \right). \quad (\text{E-2})$$

Replacing for  $de_S^*/db_S$  in (??), we obtain that

$$1 + \left( \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right) \frac{de_S^*}{db_S} = \left( \frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*} \right)^{-1} \left[ \frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*} + \left( \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right) \frac{\partial^2 \pi}{\partial e_S \partial b_S} \Big|_{e_S^*} \right]. \quad (\text{E-3})$$

Replacing for  $\frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*}$  (from (16)) and  $\frac{\partial^2 \pi}{\partial e_S \partial b_S} \Big|_{e_S^*}$  (from (20)), we obtain that the term into brackets in (E-3) is equal to

$$\left[ -C''_S(e_S^*) + \alpha_S x L \frac{d^2 q}{d^2 e_S} \Big|_{e_S^*} \right] D_B + 3 \left[ \alpha_S x L \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right] \frac{dD_B}{de_S} \Big|_{e_S^*} + M_S \frac{d^2 D_B}{d^2 e_S} \Big|_{e_S^*},$$

where

$$M_S = b_S - m - \alpha_S x L(1 - q^*) - C_S(e_S^*).$$

As  $\alpha_S x L \frac{dq}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \leq 0$ ,  $\frac{dD_B}{de_S} \Big|_{e_S^*} \geq 0$  from (17) and  $\frac{d^2 D_B}{d^2 e_S} \Big|_{e_S^*} \leq 0$  from (18), it follows that the term into brackets in (??) is negative. As  $\frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*} \leq 0$ , we can conclude that

$$1 + \left( \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right) \frac{de_S^*}{db_S} \geq 0.$$

It follows from (E-2) that

$$\frac{\partial \widehat{b_S}}{\partial \alpha_S} \geq 0.$$

Therefore, the probability that a merchant accepts the EPI decreases with the level of liability that is borne by the merchants.

### Impact of the transaction benefit received by merchants on EPI acceptance:

Similarly, we have that

$$\frac{\partial \widehat{b_S}}{\partial f} \left[ 1 + \left( \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right) \frac{de_S^*}{db_S} \right] = \frac{de_S^*}{df} \left( C'_S(e_S^*) - \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} \right).$$

As  $de_S^*/df \geq 0$ , it follows that  $\partial \widehat{b_S} / \partial f \geq 0$ .

**Impact of the transaction fees on EPI acceptance:** We also have that

$$\begin{aligned} \frac{\partial \widehat{b}_S}{\partial m} \left[ 1 + \left( \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} - C'_S(e_S^*) \right) \frac{de_S^*}{db_S} \right] &= 1 + \frac{de_S^*}{dm} \left( C'_S(e_S^*) - \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} \right) \\ &= \frac{\frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*} + \frac{dD_B}{de_S} \left( C'_S(e_S^*) - \alpha_S x L \frac{dq^*}{de_S} \Big|_{e_S^*} \right)}{\frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*}} \geq 0. \end{aligned}$$

It follows that  $\partial \widehat{b}_S / \partial m \geq 0$ .

**Appendix F: Proof of Proposition 1.** We start by determining the variation of the expected loss with the consumer fee. To that end, we denote by  $\mu(b_S, f, m, \alpha_S, \alpha_B)$  the function defined by

$$\mu(b_S, f, m, \alpha_S, \alpha_B) = (1 - q^*)h(b_S)(1 - H_B(f + \alpha_B x L(1 - q^*))).$$

From (6),

$$EL_P = \alpha_P x L \int_{\widehat{b}_S}^{\overline{b}_S} \mu(b_S, f, m, \alpha_S, \alpha_B) db_S.$$

Hence, we have that<sup>26</sup>

$$\frac{\partial EL_P}{\partial f} = \alpha_P x L \left[ \frac{-\partial \widehat{b}_S}{\partial f} \mu(\widehat{b}_S, f, m, \alpha_S, \alpha_B) + \int_{\widehat{b}_S}^{\overline{b}_S} \frac{\partial \mu(b_S, f, m, \alpha_S, \alpha_B)}{\partial f} db_S \right],$$

where

$$\begin{aligned} \frac{\partial \mu(b_S, f, m, \alpha_S, \alpha_B)}{\partial f} &= \frac{-dq}{de_S} \frac{\partial e_S^*}{\partial f} (1 - H_B(f + \alpha_B x L(1 - q^*))) h(b_S) \left[ 1 - \frac{(1 - q^*) \alpha_B x L h_B}{1 - H_B} \right] + \\ &\quad - (1 - q^*) h(b_S) h_B(f + \alpha_B x L(1 - q^*)). \end{aligned}$$

From Lemma 3, we have  $\partial e_S^* / \partial f \geq 0$ . We also have that  $dq/de_S \geq 0$ . From assumption (A2), we have

$$1 - \frac{(1 - q^*) \alpha_B x L h_B}{1 - H_B} \geq 0.$$

It follows that  $\partial \mu(b_S, f, m, \alpha_S, \alpha_B) / \partial f \leq 0$ . Since, from Lemma 4,  $\partial \widehat{b}_S / \partial f \geq 0$ , we conclude that  $\partial EL / \partial f \leq 0$ .

<sup>26</sup>The conditions to use the Leibniz rule apply.

We now determine the variations of the expected loss with the merchant fee. We have

$$\frac{\partial EL_P}{\partial m} = \alpha_P x L \left[ \underbrace{\frac{-\partial \hat{b}_S}{\partial m} \mu(\hat{b}_S, f, m, \alpha_S, \alpha_B)}_{TermA} + \underbrace{\int_{\hat{b}_S}^{\bar{b}_S} \frac{\partial \mu(b_S, f, m, \alpha_S, \alpha_B)}{\partial m} db_S}_{TermB} \right],$$

where

$$\frac{\partial \mu(b_S, f, m, \alpha_S, \alpha_B)}{\partial m} = \frac{-dq}{de_S} \frac{\partial e_S^*}{\partial m} (1 - H_B(f + \alpha_B x L(1 - q^*))h(b_S) \left[ 1 - \frac{(1 - q^*)\alpha_B x L h_B}{1 - H_B} \right] \geq 0.$$

From Lemma 3, we have  $\partial e_S^*/\partial m \leq 0$ . From Lemma 4,  $\partial \hat{b}_S/\partial m \geq 0$ . From Assumption (A2), we have

$$1 - \frac{(1 - q^*)\alpha_B x L h_B}{1 - H_B} \geq 0.$$

It follows that term A is negative, whereas term B is positive. Therefore, an increase in the merchant fee has an ambiguous impact on the expected loss that is borne by the payment platform.

Let us now study how the level of liability that is borne by merchants impacts the expected loss. We have

$$\frac{\partial EL_P}{\partial \alpha_S} = -\frac{EL_P}{\alpha_P} + \alpha_P x L \left[ \underbrace{\frac{-\partial \hat{b}_S}{\partial \alpha_S} \mu(\hat{b}_S, f, m, \alpha_S, \alpha_B)}_{TermC} + \underbrace{\int_{\hat{b}_S}^{\bar{b}_S} \frac{\partial \mu(b_S, f, m, \alpha_S, \alpha_B)}{\partial \alpha_S} db_S}_{TermD} \right],$$

where

$$\frac{\partial \mu(b_S, f, m, \alpha_S, \alpha_B)}{\partial \alpha_S} = \frac{-dq}{de_S} \frac{\partial e_S^*}{\partial \alpha_S} (1 - H_B(f + \alpha_B x L(1 - q^*))h(b_S) \left[ 1 - \frac{(1 - q^*)\alpha_B x L h_B}{1 - H_B} \right] \leq 0.$$

From Assumption (A2),

$$1 - \frac{(1 - q^*)\alpha_B x L h_B}{1 - H_B} \geq 0.$$

As  $dq/de_S \geq 0$ , and since  $\partial \hat{b}_S/\partial \alpha_S \geq 0$  from Lemma 4, it follows that

$$\frac{\partial EL_P}{\partial \alpha_S} \leq 0.$$

## Appendix G: Second-order conditions if $\alpha_B = 0$ .

**Appendix G-A: second-order conditions if the payment platform chooses the transaction prices.** We provide here the second-order conditions of profit maximisation if



$\alpha_B = 0$ . The first-order conditions of profit maximisation are

$$\frac{\partial \pi_P}{\partial m} = D_B(f) [D_S(b_S^m) - M_P h_S(b_S^m)] = 0, \quad (21)$$

and

$$\frac{\partial \pi_P}{\partial f} = D_S(b_S^m) [D_B(f) - M_P h_B(f)] = 0. \quad (22)$$

The second derivatives of the platform's profit with respect to the prices and the liability level are

$$\begin{aligned} \frac{\partial^2 \pi_P}{\partial m^2} &= -2h_S D_B - h'_S D_B M_P, \\ \frac{\partial^2 \pi_P}{\partial f^2} &= -2h_B D_S - h'_B D_S M_P, \\ \frac{\partial^2 \pi_P}{\partial m \partial f} &= -h_B D_S - h_S D_B + M_P h_S h_B, \\ \frac{\partial^2 \pi_P}{\partial m \partial \alpha_S} &= xL(1 - q^*) \frac{\partial^2 \pi_P}{\partial m^2} - (1 - \alpha_S) xL \frac{\partial q^*}{\partial \alpha_S} h_S D_B, \\ \frac{\partial^2 \pi_P}{\partial f \partial \alpha_S} &= xL(1 - q^*) \frac{\partial^2 \pi_P}{\partial m \partial f} - (1 - \alpha_S) xL \frac{\partial q^*}{\partial \alpha_S} h_B D_S, \\ \frac{\partial^2 \pi_P}{\partial \alpha_S^2} &= -2xL D_B h_S xL(1 - q^*) \left[ 1 - q^* + (1 - \alpha_S) \frac{\partial q^*}{\partial \alpha_S} \right] + M_P D_B \left[ xL h_S \frac{\partial q^*}{\partial \alpha_S} - (xL(1 - q^*))^2 h'_S \right] \\ &\quad + xLV_P \left[ -2 \frac{\partial q^*}{\partial \alpha_S} + (1 - \alpha_S) \left\{ \frac{\partial^2 q}{\partial e_S^2} \left( \frac{\partial e_S}{\partial \alpha_S} \right)^2 + \frac{\partial q}{\partial e_S} \frac{\partial^2 e_S}{\partial \alpha_S^2} \right\} \right]. \end{aligned} \quad (23)$$

We denote by  $\det M$  the determinant of the Hessian matrix at the profit maximising transaction fees. It can be checked that the second-order conditions of profit maximisation are verified as  $h'_S \geq 0$  and  $h'_B \geq 0$ . From (21) and (22), we have that, at the profit maximising prices,  $D_S = M_P h_S$  and  $D_B = M_P h_B$ . Therefore, we have

$$\det M|_{(f^*, m^*)} = 2h_S h_B D_S D_B + 2h'_B D_B D_S^2 + 2h'_S D_S D_B^2 + h'_S h'_B D_B D_S M_P^2 + h_S^2 D_B^2 > 0, \quad (24)$$

and

$$\frac{\partial^2 \pi}{\partial m^2} \Big|_{(f^*, m^*)} < 0,$$

which proves that the conditions for a maximum to exist at  $(f^*, m^*)$  hold.

**Appendix G-B: second-order conditions if the payment platform chooses the transaction prices and the level of liability for merchants.** We provide here the conditions under which the second-order conditions are verified at  $x^* = (f^*; m^*; \alpha_S^*)$  by computing

the coefficients of the Hessian matrix.

Denoting the Hessian matrix at  $x^* = (f^*; m^*; \alpha_S^*)$  by  $H = \begin{pmatrix} a_1 & b & c \\ b & a_2 & d \\ c & d & a_3 \end{pmatrix}$ , the second-order conditions are verified if  $a_1 \leq 0$ ,  $a_2 \leq 0$ ,  $a_1 a_2 - b^2 \geq 0$ ,  $a_1 a_3 - c^2 \geq 0$ ,  $a_3 a_2 - d^2 \geq 0$  and  $\det H \leq 0$  (See hereafter). If these conditions are verified, this proves that the Hessian matrix is semi-definite negative at  $x^* = (f^*; m^*; \alpha_S^*)$ .

Let us start by the case in which there is an interior solution. From (23), as  $h'_S$  and  $h'_B$  are positive, we have that  $a_1 \leq 0$  and  $a_2 \leq 0$ . We already proved in Appendix G-A that  $a_1 a_2 - b^2 \geq 0$ . We now prove that  $a_1 a_3 - c^2 \geq 0$  and that  $a_3 a_2 - d^2 \geq 0$ .

At  $x^* = (f^*; m^*; \alpha_S^*)$ , if the solution is interior, from (21) and (22), we have that  $D_S = M_P h_S$  and  $D_B = M_P h_B$ . The first-order condition of profit maximisation with respect to  $\alpha_S$  is

$$\frac{\partial \pi_P}{\partial \alpha_S} = (f + m - c) \frac{\partial V_P}{\partial \alpha_S} - \frac{\partial EL_P}{\partial \alpha_S} = 0.$$

From (7), we have that

$$\frac{\partial EL_P}{\partial \alpha_S} = -xL(1 - q^*)V_P + (1 - \alpha_S)xLq^* \frac{\partial V_P}{\partial \alpha_S}.$$

From (5), we have that  $-\partial V / \partial \alpha_S = D_B(f)h_S(\widehat{b}_S)xL(1 - q^*)$ . Therefore, the first-order condition with respect to  $\alpha_S$  writes

$$M_P h_S D_B x L (1 - q^*) = x L D_B D_S \left( 1 - q^* + (1 - \alpha_S) \frac{dq}{d\alpha_S} \right).$$

As at  $x^* = (f^*; m^*; \alpha_S^*)$  we have  $D_S = M_P h_S$ , in interior solution, we have that

$$xL(1 - q^*) = xL \left( 1 - q^* + (1 - \alpha_S) \frac{dq}{d\alpha_S} \right),$$

that is

$$\left. \frac{dq}{d\alpha_S} \right|_{x^*} = 0.$$

It follows that, in an interior solution, the payment platform chooses the level of liability that maximises the probability of fraud detection.

We denote by

$$\mu = -2 \frac{\partial q^*}{\partial \alpha_S} + (1 - \alpha_S) \left\{ \frac{\partial^2 q}{\partial e_S^2} \left( \frac{\partial e_S}{\partial \alpha_S} \right)^2 + \frac{\partial q}{\partial e_S} \frac{\partial^2 e_S}{\partial \alpha_S^2} \right\}. \quad (\text{GB-1})$$

**Lemma 6** We have  $\partial^2 e_S^* / \partial \alpha_S^2 \leq 0$ .

**Proof.** From the implicit function theorem, we have

$$\begin{aligned} \frac{\partial e_S^*}{\partial \alpha_S} &= - \left( \frac{\partial^2 \pi}{\partial^2 e_S} \Big|_{e_S^*} \right)^{-1} \left( \frac{\partial^2 \pi}{\partial e_S \partial \alpha_S} \Big|_{e_S^*} \right) \\ &= \frac{xL(\partial q / \partial e_S) D_B}{D_B(\alpha_S xL \frac{d^2 q}{de_S^2} \Big|_{e_S^*} - C_S''(e_S^*))} \\ &= \frac{xL(\partial q / \partial e_S)}{(\alpha_S xL \frac{d^2 q}{de_S^2} \Big|_{e_S^*} - C_S''(e_S^*))}. \end{aligned}$$

It follows that

$$\frac{\partial^2 e_S^*}{\partial \alpha_S^2} = \frac{xLN}{(\alpha_S xL \frac{d^2 q}{de_S^2} \Big|_{e_S^*} - C_S''(e_S^*))^2},$$

where

$$\begin{aligned} N &= xL \left( -\alpha_S \frac{d^2 q}{de_S^2} \Big|_{e_S^*} + C_S''(e_S^*) \right) \frac{d^2 q}{de_S^2} \Big|_{e_S^*} \frac{\partial e_S}{\partial \alpha_S} \\ &\quad - \left[ -\alpha_S xL \frac{d^3 q}{de_S^3} \Big|_{e_S^*} \frac{\partial e_S}{\partial \alpha_S} + C_S'''(e_S^*) \right] xL \frac{dq}{de_S} \Big|_{e_S^*}. \end{aligned}$$

Since  $\frac{d^3 q}{de_S^3} \Big|_{e_S^*} \leq 0$ ,  $\frac{d^2 q}{de_S^2} \Big|_{e_S^*} \leq 0$ , and  $C_S'''(e_S^*) \geq 0$ , we have  $N \leq 0$ . Therefore, we can conclude that  $\partial^2 e_S / \partial \alpha_S^2 \leq 0$ . ■

Since  $\partial^2 e_S / \partial \alpha_S^2 \leq 0$ ,  $\partial q / \partial e_S \geq 0$  and  $\partial^2 q / \partial e_S^2 \leq 0$ , from (GB-1), we have  $\mu \leq 0$ . As  $\frac{dq}{d\alpha_S} \Big|_{x^*} = 0$  and from (23), we have that

$$\begin{aligned} \frac{\partial^2 \pi_P}{\partial \alpha_S^2} \Big|_{x^*} &= -(xL(1 - q^*))^2 [2h_S + M_P h_S'] D_B + xLV_P \mu, \\ \frac{\partial^2 \pi_P}{\partial \alpha_S \partial f} \Big|_{x^*} &= -xL(1 - q^*) h_S D_B, \end{aligned}$$

and

$$\frac{\partial^2 \pi_P}{\partial \alpha_S \partial m} \Big|_{x^*} = -xL(1 - q^*) D_B (2h_S + h_S' M_P).$$

We now compute  $a_1a_3 - c^2$  and  $a_3a_2 - d^2$  at  $x^* = (f^*; m^*; \alpha_S^*)$ . We have

$$\begin{aligned} a_1a_3 - c^2 &= \left( \frac{\partial^2 \pi_P}{\partial f^2} \Big|_{x^*} \right) \left( \frac{\partial^2 \pi_P}{\partial \alpha_S^2} \Big|_{x^*} \right) - \left( \frac{\partial^2 \pi_P}{\partial \alpha_S \partial f} \Big|_{x^*} \right)^2 \\ &= D_B^2 [xL(1 - q^*)]^2 (3h_S^2 + (M_P h'_S)^2 + 4M_P h'_S h_S) - D_B^2 D_S \mu x L (2h_S + M_P h'_S) \geq 0. \end{aligned}$$

We also have

$$\begin{aligned} a_3a_2 - d^2 &= \left( \frac{\partial^2 \pi_P}{\partial m^2} \Big|_{x^*} \right) \left( \frac{\partial^2 \pi_P}{\partial \alpha_S^2} \Big|_{x^*} \right) - \left( \frac{\partial^2 \pi_P}{\partial \alpha_S \partial m} \Big|_{x^*} \right)^2 \\ &= -D_B^2 D_S \mu x L (2h_S + M_P h'_S) \geq 0. \end{aligned}$$

We now show that  $\det H \leq 0$  at  $x^* = (f^*; m^*; \alpha_S^*)$ . From the rule of Sarrus, we have

$$\begin{aligned} \det H &= a_1a_2a_3 + 2bdc - c^2a_2 - b^2a_3 - d^2a_1 \\ &= a_1(a_3a_2 - d^2) + 2bdc - c^2a_2 - b^2a_3. \end{aligned}$$

At  $x^* = (f^*; m^*; \alpha_S^*)$ , since  $a_1 = -D_S (2h_B + M_P h'_B)$ , we have

$$a_1(a_3a_2 - d^2) = D_B^2 D_S^2 \mu x L (2h_S + M_P h'_S) (2h_B + M_P h'_B).$$

We also have

$$2bdc = -2(xL)^2(1 - q^*)^2 h_S^2 D_B^3 (2h_S + M_P h'_S),$$

and

$$-c^2a_2 - b^2a_3 = 2(xL)^2(1 - q^*)^2 h_S^2 D_B^3 (2h_S + M_P h'_S) - \mu x L D_B^3 D_S h_S^2.$$

Using the fact that, at  $x^* = (f^*; m^*; \alpha_S^*)$ , we have  $M_P h_S = D_S$  and  $M_P h_B = D_B$ , we obtain that

$$\det H = D_B^2 D_S \mu x L M_P [3h_B h_S^2 + h'_S h'_B M_P^2 h_S + 2h_S h_B h'_S M_P + 2h_S^2 h'_B M_P]. \quad (25)$$

Since  $\mu \leq 0$ , we can conclude that  $\det H \leq 0$  at  $x^* = (f^*; m^*; \alpha_S^*)$ . Therefore, the Hessian matrix is semi-definite negative at  $x^* = (f^*; m^*; \alpha_S^*)$  and the second-order conditions are verified at  $x^* = (f^*; m^*; \alpha_S^*)$ .

**Appendix H: An illustration of Proposition 2.** We make the following assumptions:  $C_S(e_S) = k(e_S)^2/2$ ,  $q(e_S) = \gamma e_S$ , uniform distributions on  $[0, 1]$  for  $b_S$  and  $b_B$ . In this case, from equation (4), we have

$$e_S^* = \frac{\alpha_S x L \gamma}{k},$$

where  $\alpha_S x L \gamma^2 / k \leq 1$ . The merchant's effort increases with the liability level, the probability that there is a fraudulent transaction, the losses borne by the participants, and the marginal impact of investments on the probability of fraud detection. The probability that a merchant detects a fraudulent transaction is implicitly defined by

$$q(e_S^*) = (\alpha_S x L \gamma^2) / k.$$

In this case, the demands are  $D_B = 1 - f$ , and  $D_S = 1 - m - \alpha_S x L + \frac{(\alpha_S x L \gamma)^2}{2k}$ . Using the standard price structure/ratio formula, we find that the prices verify

$$f = m + \alpha_S x L - \frac{(\alpha_S x L \gamma)^2}{2k},$$

and

$$\frac{f + m - c - (1 - \alpha_S) x L (1 - q)}{f} = \frac{1 - f}{f}. \quad 27$$

Solving for  $f$  and  $m$ , we obtain that

$$m = \frac{1 + c + x L (1 - 3\alpha_S) + \frac{(x L \gamma)^2}{k} (2\alpha_S^2 - \alpha_S)}{3},$$

and

$$f = \frac{1 + c + x L + \frac{(\alpha_S^2 - 2\alpha_S)(x L \gamma)^2}{2k}}{3}.$$

We can compute the marginal merchant

$$\begin{aligned} \widehat{b}_S &= m + \alpha_S x L - \frac{(\alpha_S x L \gamma)^2}{2k} \\ &= \frac{1 + c + x L + \frac{(\alpha_S^2 - 2\alpha_S)(x L \gamma)^2}{2k}}{3}. \end{aligned}$$

The merchant demand is

$$D_S(\widehat{b}_S) = \frac{2(1 + c) - x L - \frac{(\alpha_S^2 - 2\alpha_S)(x L \gamma)^2}{2k}}{3}.$$

If  $\alpha_S$  is chosen by the payment platform (at the same stage as the prices), we have that

$$\frac{\partial \pi_P}{\partial \alpha_S} = M_P \left[ \frac{\partial D_S(\hat{b}_S)}{\partial \alpha_S} D_B(f) \right] + \frac{\partial M_P}{\partial \alpha_S} D_B(f) D_S(\hat{b}_S).$$

As  $M_P = 1 - f = D_B = D_S$  at the optimal prices, we have

$$\frac{\partial \pi_P}{\partial \alpha_S} = 2M_P D_B(f) \frac{\partial D_S(\hat{b}_S)}{\partial \alpha_S} \geq 0.$$

In this case, we find that the platform's profit is maximised by choosing  $\alpha_S = 1$ .

## Appendix I: Impact of the merchants' liability on transaction prices.

**Appendix I-A: impact of the merchants' liability on transaction prices (general case if  $\alpha_B = 0$ ).** In this Appendix, we examine how the level of liability borne by merchants impacts the transaction fees that are chosen by the payment platform, if the zero liability rule applies for consumers. By differentiating equations (21) and (22) that define the first-order conditions with respect to  $\alpha_S$ , we obtain that

$$\frac{\partial^2 \pi_P}{\partial m^2} \frac{\partial m^*}{\partial \alpha_S} + \frac{\partial^2 \pi_P}{\partial m \partial f} \frac{\partial f^*}{\partial \alpha_S} + \frac{\partial^2 \pi_P}{\partial m \partial \alpha_S} = 0, \quad (26)$$

and

$$\frac{\partial^2 \pi_P}{\partial f^2} \frac{\partial f^*}{\partial \alpha_S} + \frac{\partial^2 \pi_P}{\partial m \partial f} \frac{\partial m^*}{\partial \alpha_S} + \frac{\partial^2 \pi_P}{\partial f \partial \alpha_S} = 0. \quad (27)$$

Solving for  $\partial m^*/\partial \alpha_S$  and  $\partial f^*/\partial \alpha_S$  in (26) and (27), we obtain that

$$\frac{\partial m^*}{\partial \alpha_S} = \frac{1}{\det M} \left[ xL(1 - q^*)(-\det M) - (1 - \alpha_S)xL \frac{\partial q^*}{\partial \alpha_S} R \right],$$

and

$$\frac{\partial f^*}{\partial \alpha_S} = \frac{1}{\det M} \left[ -(1 - \alpha_S)xL \frac{\partial q^*}{\partial \alpha_S} T \right],$$

where

$$R = h_B D_S \frac{\partial^2 \pi_P}{\partial m \partial f} - h_S D_B \frac{\partial^2 \pi}{\partial f^2},$$

and

$$T = h_S D_B \frac{\partial^2 \pi_P}{\partial m \partial f} - h_B D_S \frac{\partial^2 \pi_P}{\partial m^2}.$$

We proved in Appendix G-A that  $\det M \geq 0$ . We now prove that  $R \geq 0$  and  $T \geq 0$ . We have

$$R = -h_B^2 D_S^2 + h_B h_S D_B D_S + M_P h_B^2 h_S D_S + h_S h'_B D_S D_B M_P,$$

and

$$T = h_B h_S D_B D_S - h_S^2 D_B^2 + M_P h_S^2 h_B D_B + h_B h'_S D_B D_S M_P$$

Using the first-order condition, we have that, at the profit maximising prices,  $M_P h_S = D_S$  and  $M_P h_B = D_B$ . It follows that, at the profit maximising prices,

$$R = h_B h_S D_B D_S + h_S h'_B D_S D_B M_P,$$

and

$$T = h_B h_S D_B D_S + h_B h'_S D_B D_S M_P.$$

Since  $h'_S$  and  $h'_B$  are positive, we have  $R \geq 0$  and  $T \geq 0$ . As  $\partial q^*/\partial \alpha_S \geq 0$  and  $\det M > 0$ , it follows that  $\partial m^*/\partial \alpha_S \leq 0$  and  $\partial f^*/\partial \alpha_S \leq 0$ .

Note that, since  $\widehat{b}_S = m + \alpha_S x L(1 - q^*) + C_S(e_S^*)$ , we have

$$\begin{aligned} \frac{d\widehat{b}_S}{d\alpha_S} &= \frac{\partial \widehat{b}_S}{\partial \alpha_S} + \frac{\partial m^*}{\partial \alpha_S} \\ \frac{d\widehat{b}_S}{d\alpha_S} &= \frac{1}{\det M} \left[ -(1 - \alpha_S) x L \frac{\partial q^*}{\partial \alpha_S} R \right] \leq 0, \end{aligned} \quad (28)$$

as  $\partial \widehat{b}_S / \partial \alpha_S = x L(1 - q^*)$ .

#### Appendix I-B: Application to the case of uniform distributions for $b_B$ and $b_S$ .

If  $b_B$  and  $b_S$  are uniformly distributed on  $[0, 1]$ , from the first order conditions, at the profit maximising prices, we have  $D_B = D_S = M_P$ . In this case, we have  $R = T = D_B^2$ . Therefore, from (24), we have  $\det M = 3D_B^2$ . It follows that, in this example, we have

$$\frac{d\widehat{b}_S}{d\alpha_S} = \frac{df}{d\alpha_S} = \frac{-(1 - \alpha_S)}{3} x L \frac{\partial q^*}{\partial \alpha_S}. \quad (29)$$

It follows from (29) that

$$\frac{d^2 \widehat{b}_S}{d\alpha_S^2} = \frac{d^2 f}{d\alpha_S^2} = \frac{xL}{3} \left[ \frac{\partial q^*}{\partial \alpha_S} - (1 - \alpha_S) \frac{\partial^2 q^*}{\partial^2 \alpha_S} \right] \geq 0. \quad (30)$$

From Lemma 6, we have  $\partial^2 q^* / \partial^2 \alpha_S \leq 0$ . Therefore, we can conclude that  $d^2 \widehat{b}_S / d\alpha_S^2 \geq 0$  in the case of uniform distributions on  $[0, 1]$  for the transactional benefits.

## Appendix J: Social welfare analysis.

**Appendix J-A: Variation of the consumer and the merchant surplus with the level of liability borne by merchants.** We start by computing the consumer surplus. Consumers who pay cash do not obtain any surplus from making a transaction, as a monopolistic merchant sets a price  $p^* = v$ . A consumer of transactional benefit  $b_B$  who pays with the EPI obtains a surplus

$$b_B - f - \alpha_B x L(1 - q^*).$$

Agregating this expression over all  $b_B \in [f + \alpha_B x L(1 - q^*), \bar{b}_B]$  and over all  $b_S \in [\widehat{b}_S, \bar{b}_S]$ , we obtain the aggregate consumer surplus, that is

$$S_B = \int_{\widehat{b}_S}^{\bar{b}_S} h(b_S) E(b_B - f - \alpha_B x L(1 - q^*)/b_B \geq f + \alpha_B x L(1 - q^*)) db_S,$$

where  $E(b_B - f - \alpha_B x L(1 - q^*)/b_B \geq f + \alpha_B x L(1 - q^*))$  denotes the mathematical expectancy conditional on  $b_B \geq f + \alpha_B x L(1 - q^*)$ . We have

$$\frac{\partial S_B}{\partial \alpha_S} = X + Y,$$

where

$$\begin{aligned} X &= \frac{-d\widehat{b}_S}{d\alpha_S} h(\widehat{b}_S) E(b_B - f - \alpha_B x L(1 - q^*)/b_B \geq f + \alpha_B x L(1 - q^*)), \\ Y &= \int_{\widehat{b}_S}^{\bar{b}_S} h(b_S) \frac{\partial}{\partial \alpha_S} E(b_B - f - \alpha_B x L(1 - q^*)/b_B \geq f + \alpha_B x L(1 - q^*)) db_S, \end{aligned}$$

where from the Leibniz rule,

$$\begin{aligned} \frac{\partial}{\partial \alpha_S} E(b_B - f - \alpha_B x L(1 - q^*)/b_B \geq \widehat{b}_B) &= \frac{\partial}{\partial \alpha_S} \int_{\widehat{b}_B}^{\bar{b}_B} (b_B - f - \alpha_B x L(1 - q^*)) h_B(b_B) db_B \\ &= \int_{\widehat{b}_B}^{\bar{b}_B} \left( -\frac{\partial f^*}{\partial \alpha_S} + \alpha_B x L \frac{dq}{de_S} \frac{\partial e_S}{\partial \alpha_S} \right) h_B(b_B) db_B \geq 0. \end{aligned}$$

**First case  $\alpha_B = 0$ .** In this case, from proposition 5, the transaction fees decrease with the level of liability that is borne by merchants. Therefore,  $Y$  is positive. Term  $X$  is also positive, since  $d\widehat{b}_S/d\alpha_S \leq 0$  from (28). It follows that the consumer surplus increases with the level of liability that is borne by the merchants.

**Second case:  $\alpha_B \neq 0$  [TO DO]**

Similarly, we compute the aggregate merchant surplus by aggregating the merchants' profit



for all  $b_S \in [\underline{b_S}, \overline{b_S}]$ . We have

$$S_S = (v-d)(\overline{b_S} - \underline{b_S}) + \int_{\underline{b_S}}^{\overline{b_S}} h(b_S)(b_S - m - \alpha_S xL(1-q^*) - C_S(e_S^*)) (1 - H_B(f + \alpha_B xL(1-q^*))) db_S.$$

From the Leibniz rule, we have

$$\begin{aligned} \frac{\partial S_S}{\partial \alpha_S} &= \int_{\underline{b_S}}^{\overline{b_S}} h(b_S) \frac{\partial}{\partial \alpha_S} \{ (b_S - m - \alpha_S xL(1-q^*) - C_S(e_S^*)) (1 - H_B(f + \alpha_B xL(1-q^*))) \} db_S \\ &= \int_{\underline{b_S}}^{\overline{b_S}} h(b_S) \left\{ - \left[ \frac{\partial m^*}{\partial \alpha_S} + xL(1-q^*) \right] D_B(\widehat{b_B}) + (b_S - m - \alpha_S xL(1-q^*) - C_S(e_S^*)) h'_B(\widehat{b_B}) \frac{dq^*}{d\alpha_S} \right\} db_S.^2 \end{aligned}$$

**First case**  $\alpha_B = 0$ . In this case, from proposition 5, the transaction fees decrease with the level of liability that is borne by merchants. From (28), we have  $\partial m^* / \partial \alpha_S + xL(1-q^*) \leq 0$ . It follows that the merchant surplus increases with the level of liability that is borne by merchants.

**Second case:**  $\alpha_B \neq 0$  [TO DO]

**Appendix J-B: The social welfare maximising level of liability if  $\alpha_B = 0$ .** We start by proving that the payment platform' profit is concave in  $\alpha_S$  at the profit maximising prices  $(f^*, m^*)$ , which are chosen at stage 2 (after a benevolent social planner chooses the liability level for merchants). From (23), we have

$$\begin{aligned} \frac{\partial^2 \pi_P}{\partial \alpha_S^2} &= -2xLD_B h_S xL(1-q^*) \left[ 1 - q^* + (1 - \alpha_S) \frac{\partial q^*}{\partial \alpha_S} \right] + M_P D_B \left[ xL h_S \frac{\partial q^*}{\partial \alpha_S} - (xL(1-q^*))^2 h'_S \right] \\ &\quad + xLV_P \left[ -2 \frac{\partial q^*}{\partial \alpha_S} + (1 - \alpha_S) \left\{ \frac{\partial^2 q}{\partial e_S^2} \left( \frac{\partial e_S}{\partial \alpha_S} \right)^2 + \frac{\partial q}{\partial e_S} \frac{\partial^2 e_S}{\partial \alpha_S^2} \right\} \right]. \end{aligned}$$

From Appendix J-A, at the profit maximising prices, we have that  $M_P h_B = D_B$  and  $M_P h_S = D_S$ . It follows that

$$\begin{aligned} \frac{\partial^2 \pi_P}{\partial \alpha_S^2} \Big|_{(f^*, m^*)} &= -2(xL)^2 D_B h_S (1-q^*) \left[ 1 - q^* + (1 - \alpha_S) \frac{\partial q^*}{\partial \alpha_S} \right] - M_P D_B (xL(1-q^*))^2 h'_S \\ &\quad + xLV_P \left[ - \frac{\partial q^*}{\partial \alpha_S} + (1 - \alpha_S) \left\{ \frac{\partial^2 q}{\partial e_S^2} \left( \frac{\partial e_S}{\partial \alpha_S} \right)^2 + \frac{\partial q}{\partial e_S} \frac{\partial^2 e_S^*}{\partial \alpha_S^2} \right\} \right]. \end{aligned}$$

Since  $h'_S \geq 0$ ,  $\partial^2 q / \partial e_S^2 \leq 0$ , and  $\partial^2 e_S^* / \partial \alpha_S^2 \leq 0$  from Lemma 6, we conclude that

$$\frac{\partial^2 \pi_P}{\partial \alpha_S^2} \Big|_{(f^*, m^*)} \leq 0.$$

We now study the concavity of the total user surplus. For this purpose we need to determine

the sign of  $\partial^2 f^*/\partial \alpha_S^2$  and  $\partial^2 \widehat{b}_S/\partial \alpha_S^2$ . With uniform distributions for  $b_B$  and  $b_S$  on  $[0, 1]$ , this sign is positive, and, from Appendix J-B, we have

$$\frac{\partial^2 f^*}{\partial \alpha_S^2} = \frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} = \frac{xL}{3} \left[ \frac{\partial q^*}{\partial \alpha_S} - (1 - \alpha_S) \frac{\partial^2 q^*}{\partial \alpha_S^2} \right] \geq 0.$$

In general, the total user surplus is not necessarily a concave function of  $\alpha_S$ . We have

$$\begin{aligned} \frac{\partial^2 S_B}{\partial \alpha_S^2} &= \left[ -\frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} h_S(\widehat{b}_S) - \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2 h'_S(\widehat{b}_S) \right] E(b_B - f - \alpha_B xL(1 - q^*)/b_B \geq \widehat{b}_B) \\ &\quad + 2 \frac{\partial \widehat{b}_S}{\partial \alpha_S} \frac{\partial f}{\partial \alpha_S} h_S(\widehat{b}_S) D_B(f) - \frac{\partial^2 f^*}{\partial \alpha_S^2} D_B(f) D_S(\widehat{b}_S), \end{aligned}$$

and

$$\frac{\partial^2 S_S}{\partial \alpha_S^2} = -\frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} D_B(f) D_S(\widehat{b}_S) + \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2 h_S(\widehat{b}_S) D_B(f).$$

With uniform distributions on  $[0, 1]$  for  $b_B$  and  $b_S$ , since  $D_B(f) = D_S(\widehat{b}_S)$ , we have that

$$\frac{\partial^2 S_B}{\partial \alpha_S^2} = -\frac{3}{2} \frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} D_B^2(f) + 2 \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2 D_B(f),$$

and

$$\frac{\partial^2 S_S}{\partial \alpha_S^2} = -\frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} D_B^2(f) + \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2 D_B(f).$$

We now prove that a sufficient condition for total user surplus to be concave in  $\alpha_S$  is that

$$C_S''(e_S) \geq \frac{(xL)^2}{3} \left( \frac{dq}{de_S} \right)^2 + xL \frac{d^2 q}{d^2 e_S}.$$

The total user surplus is a concave function of  $\alpha_S$  if and only if

$$\frac{\partial^2 S_S}{\partial \alpha_S^2} + \frac{\partial^2 S_B}{\partial \alpha_S^2} \leq 0.$$

As at the profit maximising prices, with uniform distributions,  $D_B = D_S$ , we have that, at the profit maximising prices,

$$\frac{\partial^2 S_S}{\partial \alpha_S^2} + \frac{\partial^2 S_B}{\partial \alpha_S^2} = -\frac{5}{2} \frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} D_B^2(f) + 3 \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2 D_B(f).$$

It follows that the total user surplus is a concave function of  $\alpha_S$  if and only if

$$\frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} D_B(f) \geq \frac{6}{5} \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2.$$

As  $D_B$  belongs to  $[0, 1]$ , a sufficient condition for the total surplus to be concave in  $\alpha_S$  is that

$$\frac{\partial^2 \widehat{b}_S}{\partial \alpha_S^2} \geq \frac{6}{5} \left( \frac{\partial \widehat{b}_S}{\partial \alpha_S} \right)^2.$$

From (29) and (30), this condition is equivalent to

$$\left[ \frac{\partial q^*}{\partial \alpha_S} - (1 - \alpha_S) \frac{\partial^2 q^*}{\partial^2 \alpha_S} \right] \geq \frac{(1 - \alpha_S)^2}{3} xL \left( \frac{\partial q^*}{\partial \alpha_S} \right)^2,$$

that is

$$\frac{\partial q^*}{\partial \alpha_S} \left[ 1 - \frac{(1 - \alpha_S)^2}{3} xL \left( \frac{\partial q^*}{\partial \alpha_S} \right) \right] - (1 - \alpha_S) \frac{\partial^2 q^*}{\partial^2 \alpha_S} \geq 0.$$

As  $\partial^2 q^* / \partial^2 \alpha_S \leq 0$  from Lemma 6, a sufficient condition for this inequality to hold is that

$$1 - \frac{(1 - \alpha_S)^2}{3} xL \left( \frac{\partial q^*}{\partial \alpha_S} \right) \geq 0. \quad (31)$$

If  $\alpha_B = 0$ , we have

$$\frac{\partial q^*}{\partial \alpha_S} = \frac{xL D_B \left( \frac{\partial q^*}{\partial \alpha_S} \right)^2}{-xL \frac{\partial^2 q^*}{\partial e_S^2} + C_S''(e_S)}.$$

It follows that (31) holds if

$$C_S''(e_S) \geq \frac{(xL)^2}{3} \left( \frac{\partial q^*}{\partial \alpha_S} \right)^2 + xL \frac{\partial^2 q^*}{\partial e_S^2}.$$

We denote by  $\alpha_S^P$  the level of liability that maximises the platform's profit and by  $\alpha_S^W$  the level of liability that maximises social welfare. We have

$$\frac{\partial W}{\partial \alpha_S} \Big|_{\alpha_S^P} = \frac{\partial S_S}{\partial \alpha_S} \Big|_{\alpha_S^P} + \frac{\partial S_B}{\partial \alpha_S} \Big|_{\alpha_S^P} \geq 0 = \frac{\partial W}{\partial \alpha_S} \Big|_{\alpha_S^W}$$

If  $W$  is concave in  $\alpha_S$ , it follows that  $\alpha_S^P \leq \alpha_S^W$ .

**Appendix K: The role of interchange fees.** In this section, we look at the impact of merchants' liability on profit-maximising and welfare maximising interchange fees. As con-

sumers bear no liability on fraudulent transactions, merchants' investments in fraud detection technologies do not depend on the transaction fees that are paid by the users. We have

$$\widehat{b}_S = m + \alpha_S xL(1 - q^*) + C_S(e_S^*),$$

where  $e_S^*$  solves (4). As  $m = a + c_A$ , and from the envelop theorem, we have

$$\frac{d\widehat{b}_S}{da} = 1.$$

As the acquirers make zero profit, banks' joint profit is equal to the issuers' profit,

$$\pi_I = (f^*(c_I - a) + a - c_I - (1 - \alpha_S)xL(1 - q^*))D_B(f)D_S(\widehat{b}_S).$$

Note that the level of investment that is chosen by the merchants depends neither on the transaction fees nor on the interchange fee. From the envelop theorem, as  $\left. \frac{\partial \pi_I}{\partial f} \right|_{f^*} = 0$ , we have

$$\frac{d\pi_I}{da} = \frac{\partial \pi_I}{\partial a} + \frac{\partial \pi_I}{\partial m} \frac{\partial m}{\partial a}$$

Solving for the first-order condition of profit maximisation yields

$$\frac{d\pi_I}{da} = \left[ \frac{df^*}{da} + 1 \right] D_B(f)D_S(\widehat{b}_S) - (f^*(c_I - a) + a - c_I - (1 - \alpha_S)xL(1 - q^*))D_B(f)h'_S(\widehat{b}_S).$$

The second-order condition is

$$\frac{d^2 \pi_I}{da^2} = D_B \left[ \frac{d^2 f^*}{da^2} D_S - 2 \left[ \frac{df^*}{da} + 1 \right] h'_S(\widehat{b}_S) - (f^*(c_I - a) + a - c_I - (1 - \alpha_S)xL(1 - q^*))h''_S(\widehat{b}_S) \right] \leq 0.$$

Since  $h'_S(\widehat{b}_S) \geq 0$ , a sufficient condition for the second-order condition to hold is that  $d^2 f^*/da^2 \leq 0$ . For instance, the second-order condition holds with uniform distributions on  $[0, 1]$  for  $b_B$  and  $b_S$  and if the issuer is a monopolist, as in this case  $f^* = (1 - a + c_I)/2$ .

In an interior solution, the profit maximising interchange fee is implicitly defined by

$$(f^*(c_I - a^P) + a^P - c_I - (1 - \alpha_S)xL(1 - q^*)) = \frac{D_S(\widehat{b}_S)}{h'_S(\widehat{b}_S)} \left[ \left. \frac{df^*}{da} \right|_{a^P} + 1 \right].$$

The profit maximising interchange fee reflects a trade-off between increasing the transaction volume by encouraging merchants to accept the EPI and maximising the margin per transaction. For instance, with uniform distributions on  $[0, 1]$  for  $b_B$  and  $b_S$  and if the issuer is a monopolist,

we have

$$a^P = \frac{c_I - c_A - \alpha_S xL(1 - q^*) - C_S(e_S^*)}{2} + (1 - \alpha_S)xL(1 - q^*).$$

From the implicit function theorem, we have

$$\frac{da^P}{d\alpha_S} = - \left( \frac{d^2\pi_I}{da^2} \right)^{-1} \left( \frac{\partial^2\pi_I}{\partial a \partial \alpha_S} \right),$$

where

$$\begin{aligned} \frac{\partial^2\pi_I}{\partial a \partial \alpha_S} = & -D_B xL(1 - q^*) \left[ \left( \frac{df^*}{da} \Big|_{a^P} + 1 \right) h_S(\widehat{b}_S) + (f^* + a^P - c_I - (1 - \alpha_S)xL(1 - q^*)) h'_S(\widehat{b}_S) \right] \\ & - D_B(f) h_S(\widehat{b}_S) \left[ xL(1 - q^*) + (1 - \alpha_S) \frac{dq^*}{de_S} \frac{de_S^*}{d\alpha_S} \right]. \end{aligned}$$

As  $h'_S(\widehat{b}_S) \geq 0$ ,  $\partial f/\partial a \leq 0$ , and  $\partial e_S/\partial \alpha_S \leq 0$ , we have

$$\frac{\partial^2\pi_I}{\partial a \partial \alpha_S} \leq 0.$$

It follows that the interchange fee decreases with the level of liability that is borne by merchants.

If consumers could be held liable for fraudulent transactions, the merchants' fraud prevention effort could depend on the interchange fee. In that case, the payment platform could decide to lower the interchange fee to encourage merchants to invest in fraud prevention technologies.

We now show in an example that if the interchange fee is chosen by a regulator at stage 1, the payment platform can react at stage 2 by adjusting the level of merchant liability. For instance, assume that  $b_B$  and  $b_S$  are uniformly distributed on  $[0, 1]$  and that the issuer is a monopolist. In this case, we have that  $f^* = (1 - a + c_I)/2$ . The payment platform chooses the level of liability for merchants that maximises the issuer's profit,

$$\pi_I = \left( \frac{1 + a - c_I}{2} - (1 - \alpha_S)xL(1 - q^*) \right) \left( \frac{1 + a - c_I}{2} \right) (1 - a - c_A - \alpha_S xL(1 - q^*) - C_S(e_S^*)).$$

With a linear probability such that  $q(e_S) = \gamma e_S$ , where  $0 < \gamma \leq 1$ , with a cost function such that  $C_S(e_S) = ke_S^2/2$ , we have

$$e_S^* = \frac{\alpha_S \gamma xL}{k}.$$

Solving for the first-order condition of profit maximisation with respect to  $\alpha_S$ , from the

envelop theorem, we obtain that

$$(xLr^* + (1 - \alpha_S)xL\gamma)[1 - a - c_A - \alpha_S xLr^* - C_S(e_S^*)] = \left[ \frac{1 + a - c_I}{2} - (1 - \alpha_S)xLr^* \right] xLr^*,$$

where  $r^* = 1 - q^*$ . The second-order condition writes

$$-\gamma(1 + xL)D_S(b_S^m) - 2(xL)^2(1 - q^*)(1 - q^* + \gamma(1 - \alpha_S)) - (1 - \alpha_S)(xL)^2\gamma(1 - q^*) \leq 0.$$

From the implicit function theorem,  $\partial\alpha_S/\partial a$  has the same sign as  $\partial^2\pi_I/\partial a\partial\alpha_S$ . We have

$$\frac{\partial^2\pi_I}{\partial a\partial\alpha_S} = -2xL(1 - q^*) - (1 - \alpha_S)xL\gamma \leq 0.$$

We find that the liability level that is chosen by the payment platform decreases with the level of interchange fee. This example shows that if a regulator chooses a level of interchange fee that is quite low, the platform can react by increasing the level of liability that is borne by merchants.

