Payment Evasion*

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Abstract

This paper shows that a firm can use the purchase price and the fine imposed on detected payment evaders to discriminate between unobservable consumer types. Assuming that consumers self-select into regular buyers and payment evaders, we show that the firm typically engages in second-degree price discrimination in which the purchase price exceeds the expected fine. In addition, we find that higher fines do not necessarily reduce payment evasion. We illustrate with data from fare dodging on public transportation.

Keywords: Pricing, Fine, Price Discrimination, Deterrence

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1 Introduction

Payment evasion—fraudulent consumption by nonpaying consumers—presents a major challenge for many firms.[1] There are many ways to obtain products or services without payment, including shoplifting (Yaniv 2009, Perlman and Ozinci 2014), wardrobing (Timoumi and Coughlan 2014), and digital piracy (Chellappa and Shivendu 2005, Vernik et al. 2011). In the public sector, payment evasion occurs in the form of tax evasion (Slemrod 2007), parking violations (Fisman and Miguel 2007), and—perhaps the classic example—fare dodging on public transportation (Boyd et al. 1989, Kooreman 1993, Bijleveld 2007). Surprisingly, standard price theory abstracts from payment evasion and posits the excludability of nonpaying consumers based on pricing alone. Or, as Hirshleifer et al. (2005, p. 19) put it, “To acquire a commodity buyers must be willing to pay the market price.” The implicit assumption is that the cost associated with payment evasion is high enough to exclude consumers from fraudulent consumption. Nonetheless, nonexcludability is prevalent (Novos and Waldman 1984).

We argue that nonexcludability gives rise to payment evasion, but also provides an opportunity for firms to discriminate between consumer types. The starting point of our analysis is the observation that, in many markets, firms are able to collect fines—limited to a maximum admissible level mandated by law—from detected payment evaders.[2] There are thus two demand segments to be taken into account: paying consumers and payment evaders. We develop a theoretical model in which a profit-maximizing firm chooses both the purchase price and the fine imposed on detected payment evaders.[3] Observing the price and the fine, consumers can purchase, evade payment, or choose the outside option. The extent of payment evasion is thus endogenously determined by the interplay of the choices made by the firm and by consumers.[4]

[1] For example, in the United States shoplifters steal more than $13 billion worth of goods from retailers every year (National Association for Shoplifting Prevention 2016). Similarly, consumption of digitally pirated music by U.S. internet users in 2008 is estimated to be between $7 billion and $20 billion (Frontier Economics 2011).

[2] Retailers, for instance, regularly impose in-store penalties for shoplifting. Under New York’s state law, retailers may collect a penalty “not to exceed the greater of five times the retail price of the merchandise” (N.Y. GOB. LAW §11-105).

[3] In line with Gneezy and Rustichini (2000), the fine can be viewed as the price faced by a detected payment evader.

[4] Modeling payment evasion in this way provides a natural extension of standard price theory. Alternatively, one might assume that an exogenous share of consumers are “born” payment evaders who never pay or exit the market (irrespective of price or fine). Yet, such an assumption can explain neither the emergence of payment evasion nor the choice of the price and fine in the presence of payment evasion.

We derive three key results. First, payment evasion leads to a form of second-degree price discrimination in which the purchase price exceeds the expected fine and individuals self-select into paying consumers and payment evaders. Second, the impact of an increase in the maximum admissible fine on payment evasion is ambiguous. The intuition for this result is that an increase in the fine not only has a direct negative effect on payment evasion but also generates an upward pressure on the purchase price. For payment evasion to be reduced, the direct effect must dominate the price-mediated effect. Third, price discrimination generalizes naturally to settings in which the firm does not focus on pure profit, chooses the control effort endogenously, or is overseen by a (captured) regulator. Price discrimination vanishes only with standard welfare maximization, which requires that both the purchase price and the expected fine are equal to the social cost of consumption.

We illustrate our theoretical analysis with an empirical case study of fare dodging on the *Zurich Transport Network*, one of Switzerland's largest public transport networks. First, we show that prices and fines are discriminated as predicted: regular consumers pay higher ticket prices than payment evaders pay in expectation. Second, we document that an increase in the maximum admissible fines was associated with a reduction in the control effort and the detection probability. In line with the theory on public law enforcement, we argue that the transport operator reduced the costly control effort in exchange for higher monetary fines. Third, we provide an explanation for the increase in the level and the rate of payment evasion after the increase in the maximum admissible fines. Our theory suggests that the increase in the level of payment evasion was driven by concurrent changes in the maximum admissible fines, the beliefs about the detection probability, and the size of the market. It also suggests that the increase in the rate of payment evasion was caused by a disproportionately high inflow of consumer types who are more inclined to evade payment.

This paper makes a twofold contribution. First, we introduce the notion of payment evasion into the pricing literature and show that it provides an opportunity for second-degree price discrimination in which a good is sold at different prices to purchasing consumers and payment evaders (Phlips 1983, Anderson and Dana 2009). Our analysis extends the classic Ramsey pricing rule (Ramsey 1927) to a setting where the extent of payment evasion is endogenously determined by the interplay of rational choices made by the firm and by consumers (Becker 1968, Ehrlich 1996).[5] Our model is also related to

[5]Rational consumer choices also give rise to payment evasion under pay-as-you-wish pricing (Schmidt et al. 2015, Chen et al. 2016). However, under such a pricing scheme, payment evasion is tolerated by the firm and not subject to a fine.

the analysis of damaged goods (Deneckere and McAfee 1996). The key difference is that payment evaders can be fined but not excluded from consumption. As a consequence, the firm may sustain losses from payment evasion (if the maximum admissible expected fine does not cover cost), whereas with damaged goods the firm can shut down product lines at will. Finally, our model is related to the analysis of fare evasion by Kooreman (1993). We add to this analysis by endogenizing firm decisions and considering consumer heterogeneity with respect to willingness to pay rather than risk aversion.

Second, we provide evidence on payment evasion using data from fare dodging on public transportation. Fare dodging offers an ideal opportunity to study payment evasion since we can observe large numbers of both regular consumers and detected payment evaders, something that is difficult to come by in other industries. Our empirical analysis adds to the literature on the effect of enforcement on unlawful behavior (Levitt 1997, DiTella and Schargrodsky 2004, DeAngelo and Hansen 2014) by incorporating the perspective of private (rather than public) law enforcement. It also complements empirical work on digital piracy in the music and movie industries (Rob and Waldfogel 2006, 2007, Zentner 2006, Oberholzer-Gee and Strumpf 2007, Waldfogel 2012, Peukert et al. 2015).

The remainder of the paper is organized as follows. Section 2 introduces the model and describes how consumers self-select into paying consumers, payment evaders, or non-buyers. Section 3 examines profit-maximizing payment evasion. Section 4 considers three extensions in which the firm is not limited to profit maximization, chooses the detection probability endogenously, or is overseen by a (captured) regulator. Section 5 provides empirical evidence from fare dodging. Section 6 offers conclusions and directions for future research.

2 The Model

We first introduce the decision-makers in our model: the firm and consumers. Next, we characterize self-selection by consumers and derive the demand of paying consumers and payment evaders, respectively.

2.1 Firm

We consider a firm that offers a product (or service) to paying consumers and payment evaders. The firm chooses the price p at which it sells the product and the monetary fine f that is imposed on detected payment evaders. The constant unit cost to provide the product are denoted by $c \geq 0$, and we normalize the fixed cost of operation to zero as they do not affect the choice of price and fine. We let (π, F) describe the detection technology that allows the firm to detect payment evaders with probability $\pi \in [0,1]$ after investing $F > 0$.[6] For $\pi < 1$, detection is uncertain and assumed to be equally likely for all consumers (Polinsky and Shavell 2007).

In line with Becker (1968), we assume that the monetary fine is limited by legal requirements.[7] Formally, this means that the fine set by the firm cannot exceed the maximum admissible fine $\bar{f}$, where $0 \leq \bar{f} < +\infty$.

2.2 Consumers

We consider a market with a mass N of potential consumers who observe the price p and the fine f before making a choice. Consumers have unit demand and choose among one of three options: (i) purchase the product, (ii) obtain the product but evade payment, or (iii) select the outside option (forgo consumption). When purchasing, a consumer obtains the product at price p. When evading payment, a consumer obtains the product, incurs the evasion cost $k \geq 0$, and faces the risk of being fined in amount f. The evasion cost may reflect the difficulty of obtaining the product without payment or the moral cost of evading payment (Chellappa and Shivendu 2005). Consumers are risk-neutral and have identical beliefs, $\phi \in [0,1]$, about the detection probability π. Risk-neutrality is a common assumption when stakes are small (Rabin 2000).[8]

2.3 Demand Segments

Suppose that consumers have an indirect utility function that allows them to rank the options in a consistent and unambiguous manner. Preference heterogeneity is captured by the type θ, which represents a consumer's marginal willingness to pay for quality (Mussa and Rosen 1978). Types are drawn independently from a distribution with density function $g(\theta)$ and cumulative distribution function $G(\theta)$ on $[0, +\infty)$, where $g(\theta) > 0$ for all θ, $G(0) = 0$, and $G(+\infty) = 1$. Specifically, a consumer with type θ has the indirect utility function

$$V(p, f; \theta, \phi, k) = \max\{v_P(p; \theta), v_E(f; \theta, \phi, k), 0\},$$

where $v_P(p;\theta)$ and $v_E(f;\theta,\phi,k)$ denote the conditional indirect utilities of making a purchase and evading payment, respectively. The conditional indirect utilities depend

[6] We relax the assumption of an exogenous detection probability in Section 4.2.

[7] The highest conceivable monetary fine is the wealth of a payment evader, which the firm usually cannot appropriate.

[8] In the empirical example, fare dodgers pay a fine of about 100 US$ with probability less than 1.5%.

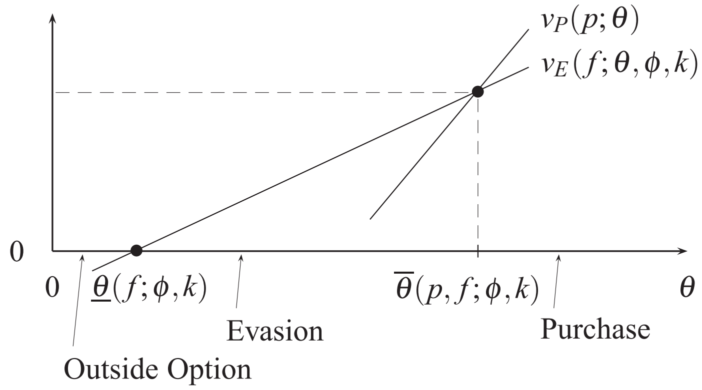

Figure 1: Cut-off Values and Demand Segments.

on the relevant prices and the consumer's type; in addition, the notation $v_E(f;\theta,\phi,k)$ captures the dependence of a payment evader's utility on the belief about the detection probability and the cost of evading payment. For convenience, we normalize the utility of the outside option to zero. We impose the following assumption.

Assumption 1. *(i) The function $v_E(f;\theta,\phi,k)$ is increasing in θ and there is $\underline{\theta} \in [0,\infty)$ such that $v_E(f;\underline{\theta},\phi,k) = 0$. (ii) The difference $v_P(p;\theta) - v_E(f;\theta,\phi,k)$ is increasing in θ and there exists $\overline{\theta} \in [\underline{\theta},\infty)$ satisfying $v_P(p;\overline{\theta}) = v_E(f;\overline{\theta},\phi,k) \geq 0$. (iii) The functions $v_P(p;\theta)$ and $v_E(f;\theta,\phi,k)$ are quasi-linear in price and expected fine, respectively.*

Assumption 1 assures that consumers self-select into one of three segments. The type $\overline{\theta}(p,f;\phi,k)$ denotes the consumer who is indifferent between purchasing and evading payment, and consumers with type $\theta \geq \overline{\theta}(p,f;\phi,k)$ purchase the product. The consumer who is indifferent between evading payment and choosing the outside option has type $\underline{\theta}(f;\phi,k)$, and consumers with type $\theta \leq \underline{\theta}(f;\phi,k)$ forgo consumption. Consequently, the remaining consumers with a type θ below $\overline{\theta}(p,f;\phi,k)$ but above $\underline{\theta}(f;\phi,k)$ evade payment, as illustrated in Figure 1.

Observe that the difference in indirect utilities is increasing in θ if paying consumers obtain a product of higher (perceived) quality than payment evaders. However, a quality difference is not necessary to generate this property: it also emerges with equal qualities if the consumer type θ interacts with the cost of evading payment k.[9] Quasi-linearity

[9] To illustrate this point, consider the conditional indirect utility functions $v_P(p;\theta) = \theta s_P - p$ and $v_E(f;\theta,\phi,k) = \theta s_E - \phi f - k$, where s_P and s_E reflect the perceived qualities (we will study this example in Section 3.3 below). Clearly, there must be a difference in perceived qualities for Assumption 1 to hold. An alternative specification of the indirect utility of evading payment is $v_E(f;\theta,\phi,k) = \theta(s_E - k) - \phi f$.

ensures that the demand functions generated from these preferences have standard properties.

The size of each demand segment is determined by the cut-off values $\underline{\theta}(f;\phi,k)$ and $\overline{\theta}(p,f;\phi,k)$, accounting for the distribution of consumer types in the population. From Assumption 1, the demand of paying consumers is given by

$$
\begin{aligned}
D(p,f;\phi,k) &= N \int\limits_{\overline{\theta}(p,f;\phi,k)}^{+\infty} g(\theta)d\theta \\
&= N[1-G(\overline{\theta}(p,f;\phi,k))]. \qquad (1)
\end{aligned}
$$

The demand of paying consumers depends on the price p and the fine f and reflects the consumers' choice between purchasing and evading payment. In addition, the demand in (1) is affected by the consumers' belief about the detection probability and the cost of evading payment. Similarly, the demand for the outside option can be expressed as

$$
\begin{aligned}
X(f;\phi,k) &= N \int\limits_{0}^{\underline{\theta}(f;\phi,k)} g(\theta)d\theta \\
&= N[G(\underline{\theta}(f;\phi,k))]. \qquad (2)
\end{aligned}
$$

Notice that demand for the outside option depends on the fine but not on the price, since it reflects the consumers' choice between evading payment and the outside option. We define payment evasion as follows.

Definition 1. *Payment evasion is the demand of consumers who evade payment and given by* $E(p,f;\phi,k) \equiv N - D(p,f;\phi,k) - X(f;\phi,k)$.

Definition 1 shows that payment evasion is endogenously determined by the interplay of the choices made by the firm and by consumers. Importantly, the presence of payment evaders allows the firm to discriminate the prices charged to different groups of consumers. Since purchasing and evading payment are substitutes, the demands of paying consumers and payment evaders are interdependent.

Our first result shows the impact of p and f on the demand functions (the proof of this and all other results is relegated to the Appendix). To simplify exposition we suppress the parameters of the demand functions from now on.

In this case, there is no need for a quality difference: the desired property holds because of the interaction between θ and k (and is reinforced when there is a quality difference).

Lemma 1. *The demand of paying consumers satisfies $D_p(p,f) < 0$ and $D_f(p,f) > 0$, and the demand for the outside option satisfies $X'(f) > 0$.*

An immediate consequence of Lemma 1 is that $E_p(p,f) > 0$ and $E_f(p,f) < 0$. The latter property illustrates the deterrence effect of the fine.

3 Profit Maximization

In this section, we first study profit-maximizing pricing. We then analyze how changes in binding maximum admissible fines affect pricing and payment evasion. Finally, we provide an example to illustrate.

3.1 Price and Fine

When some consumers evade payment, the firm deals with two interdependent demand segments: paying consumers and detected payment evaders. The firm chooses the price and the fine to maximize (expected) profit from the two segments:

$$\begin{aligned}\max_{p,f} \quad & \Pi(p,f) = (p-c)D(p,f) + (\pi f - c)E(p,f) - F \\ \text{s.t.} \quad & p \geq 0 \\ & 0 \leq f \leq \bar{f},\end{aligned}$$

where $E(p,f) = N - D(p,f) - X(f)$ by Definition 1 and F is the fixed cost of the detection technology. To put additional structure on this problem, we impose the following assumption.

Assumption 2. *The objective function is strictly concave.*

This assumption ensures that the firm's objective function Π has a unique global constrained maximizer. The necessary and sufficient Kuhn-Tucker conditions are

$$D(p^m, f^m) + (p^m - \pi f^m) D_p(p^m, f^m) = -\lambda_1, \tag{3}$$

$$(p^m - \pi f^m) D_f(p^m, f^m) + \pi(N - D(p^m, f^m) - X(f^m)) - (\pi f^m - c)X'(f^m) = -\lambda_2 + \lambda_3, \tag{4}$$

$$\lambda_1 p^m = 0, \quad \lambda_2 f^m = 0, \quad \text{and} \quad \lambda_3(f^m - \bar{f}) = 0,$$

where the λs are nonnegative multipliers associated with the inequality constraints.

The first-order conditions have intuitive interpretations. First, a marginal increase in the price p has the usual impact on the revenue from paying consumers, distorted upwards by the factor $-\pi f D_p$. This distortion arises because some paying consumers are diverted to the segment of payment evaders who can be fined in expectation, which in turn dampens the revenue reduction on the inframarginal units. Second, a marginal increase in the fine f affects the revenue from expected fines, which is distorted upwards by the factor pD_f since some payment evaders are induced to pay. In addition, the first-order conditions show that a marginal increase in p does not affect costs while a marginal increase in f does because some payment evaders are deterred and forgo consumption. We derive the following result.

Proposition 1. *Under Assumptions 1 and 2, (i) the profit-maximizing price p^m satisfies*

$$\frac{p^m - c}{p^m} = \frac{1}{\varepsilon} + \frac{\pi f^m - c}{p^m},$$

where $\varepsilon \equiv -\frac{pD_p}{D}$ denotes the price elasticity of demand; and (ii) the profit-maximizing expected fine πf^m exceeds the unit cost c at an interior solution for f and may be below unit cost at a corner solution where $f^m = \overline{f}$.

Proposition 1 demonstrates that self-selection into regular consumers and payment evaders gives rise to second-degree price discrimination (Phlips 1986, Anderson and Dana 2009) in which regular consumers pay a higher price than payment evaders pay in expectation ($p^m > \pi f^m$). That is, payment evasion allows the firm to differentiate the prices it charges to different groups of consumers.

The result also shows that the relative profit margin—the Lerner index—deviates from the inverse price elasticity of demand. If the firm can generate profit from payment evaders ($\pi f^m > c$), regular consumers "overpay" due to the presence of payment evaders.[10] This is a consequence of the fact that an increase in the price diverts some paying consumers to the segment of payment evaders who are fined in expectation. The potential to generate profit from diverted consumers creates an incentive for the firm to raise the price above the level that would otherwise be optimal. Conversely, if the maximum admissible fine prevents the firm from generating profit from payment evaders ($\pi \overline{f} < c$), regular consumers "underpay," as the loss incurred on payment evaders induces the firm to set lower prices than would otherwise be optimal.[11]

[10]This result is reminiscent of standard multiproduct monopoly pricing with interdependent demands when products are substitutes. See, for instance, Tirole (1988, p. 69).

[11]Observe that it may be profit-maximizing to sustain a loss from payment evasion (since $p^m > \pi \overline{f}$, total profit may still be positive).

3.2 Higher Admissible Fines

This section studies how changes in a binding maximum admissible fine affect the firm's pricing decisions and payment evasion by consumers. Evidently, changes in $\bar{f}$ do not affect the choices made by the firm and consumers if the maximum admissible fine is not binding. The following result holds.

Proposition 2. *Under Assumptions 1 and 2, (i) if $D_{pf} \geq 0$, the profit-maximizing price $p^m(\bar{f})$ increases in the maximum admissible fine $\bar{f}$; (ii) the impact of an increase in $\bar{f}$ on payment evasion, $E^m(\bar{f})$, is ambiguous; and (iii) if the price is fixed at p_0^m and there is an increase in the fine from $\bar{f}_0$ to $\bar{f}_1$, payment evasion decreases, and the aggregate change can be decomposed into type-specific changes*

$$E(p_0^m, \bar{f}_1) - E(p_0^m, \bar{f}_0) = -N\left[\int_{\overline{\theta}(p_0^m, \bar{f}_1)}^{\overline{\theta}(p_0^m, \bar{f}_0)} g(\theta)d\theta + \int_{\underline{\theta}(\bar{f}_0)}^{\underline{\theta}(\bar{f}_1)} g(\theta)d\theta\right].$$

Proposition 2 gives a sufficient condition under which relaxing the legal constraint on the maximum admissible fine results in a higher price (and a higher expected fine). The intuition for this result is similar to the one underlying Proposition 1. Because the expected fine for payment evaders increases, it is optimal for the firm to raise the price for paying consumers as well. In addition, Proposition 2 shows that a higher maximum fine does not necessarily reduce payment evasion. To understand this result, observe that $E^m(\bar{f}) \equiv E(p^m(\bar{f}), \bar{f})$. Even though a higher $\bar{f}$ has a direct dampening effect on payment evasion, the overall impact on payment evasion is generally ambiguous due to the upward pressure on the purchase price. However, if the resulting price increase is not too large, the direct effect dominates the price-mediated effect, and the higher fine has the expected effect on payment evasion. This holds, a fortiori, if the price is fixed at some price p_0^m: Then, the higher fine induces some high-type evaders to purchase and some low-type evaders to choose the outside option, as illustrated in Figure 2. Clearly, the reduction in payment evasion depends on the mass of types in the relevant regions of the density function.

3.3 Example

We consider a market with a unit mass of consumers who have correct beliefs about the detection probability ($\phi = \pi$), and we normalize the unit cost c to zero. Consumer types θ are drawn independently from a uniform distribution over the interval $[0,1]$, and the conditional indirect utility functions are given by $v_P(p;\theta) = \theta s_P - p$ and $v_E(f;\theta,\pi,k) =$

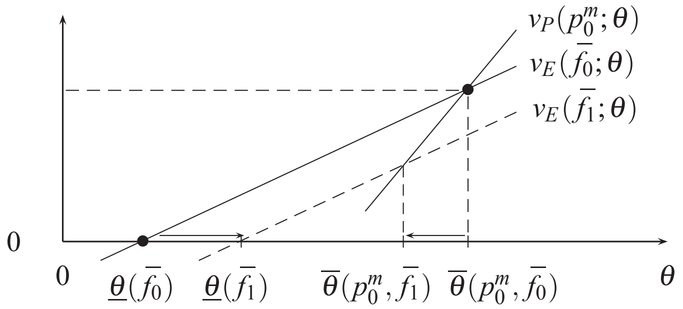

Figure 2: Deterrence Effect of a Higher Fine for a Fixed Price.

$\theta s_E - \pi f - k$. The parameters s_P and s_E are assumed to be positive and reflect the (perceived) qualities of the products obtained by paying consumers and payment evaders, respectively. In line with Assumption 1, we require that $s_P > s_E$. In addition, we impose that $\underline{\theta}(f) \leq \overline{\theta}(p,f)$, thereby restricting the evasion cost to be sufficiently small in order for payment evasion to occur:

$$k \leq \frac{ps_E - \pi f s_P}{s_P} \equiv \bar{k}.$$

The demand of paying consumers and the demand for the outside option are given by

$$D(p,f) = 1 - \frac{p - \pi f - k}{s_P - s_E} \quad \text{and} \quad X(f) = \frac{\pi f + k}{s_E},$$

respectively, and payment evasion can be derived as

$$E(p,f) = \frac{ps_E - (\pi f + k)s_P}{(s_P - s_E)s_E}.$$

The next result illustrates Propositions 1 and 2. To ensure that $\bar{k}$ is a positive number, we assume that $\bar{f} < \frac{s_E}{2\pi}$.

Corollary 1. *Suppose that $\bar{f} < \frac{s_E}{2\pi}$ and $k \leq \frac{(s_P - s_E)(s_E - 2\pi \bar{f})}{2s_P - s_E}$. Then, (i) the optimal price and fine are given by*

$$p^m = \pi \bar{f} + \frac{s_P - s_E + k}{2} \quad \textit{and} \quad f^m = \bar{f};$$

(ii) the price p^m increases in the maximum fine $\bar{f}$; and (iii) payment evasion is given by

$$E^m(\bar{f}) = \frac{1}{2} - \frac{\pi \bar{f}}{s_E} - \frac{(2s_P - s_E)k}{2(s_P - s_E)s_E}$$

and decreases in $\bar{f}$.

Corollary 1 is useful for a comparison to the standard monopoly model. If the cost of evading payment is prohibitively high ($k \geq \bar{k}$), nonpaying consumers are automatically excluded by pricing alone ($E^m(\bar{f}) = 0$). In contrast, if the cost of evading payment is low ($k < \bar{k}$), payment evasion occurs ($E^m(\bar{f}) > 0$) and is fined in expectation, leading to price discrimination ($p^m > \pi \bar{f}$). Note that increasing the maximum fine $\bar{f}$ has an unambiguous (negative) effect on payment evasion in this example.

4 Extensions

This section offers three extensions of the baseline model. First, we follow Armstrong and Sappington (2007) and study the pricing of a firm that maximizes a weighted average of profit and consumer surplus rather than pure profit. Second, we build on the theory of public law enforcement (Polinsky and Shavell 2007) and let the firm endogenously choose both the pricing and the detection probability. Third, we study how pricing is affected by regulatory capture (Laffont and Tirole 1993; Dal Bó 2006).

4.1 Beyond Profit Maximization

Often times a (public) firm does not focus on pure profit only in decision making but also takes consumer interests—captured by the consumer surplus—into account. We follow the convention of defining (expected) consumer surplus as the sum of indirect utilities across the different types of paying consumers and payment evaders.

Definition 2. *The consumer surplus is given by*

$$S(p,f) \equiv N \int_{\bar{\theta}(p,f)}^{\infty} v_P(p;\theta)g(\theta)d\theta + N\int_{\underline{\theta}(f)}^{\bar{\theta}(p,f)} v_E(f;\theta)g(\theta)d\theta.$$

To account for consumer interests, we assume that the firm maximizes a weighted average of profit and consumer surplus, $\Omega = \Pi + \alpha S$, where $\alpha \in [0,1]$ reflects the relative importance of consumer surplus (Armstrong and Sappington 2007). This formulation nests the cases of pure profit maximization ($\alpha = 0$) and standard welfare maximization ($\alpha = 1$). Specifically, the firm chooses the price p and the fine f to solve

$$\begin{aligned}
\max_{p,f} \quad & \Omega(p,f) = (p-c)D(p,f) + (\pi f - c)E(p,f) + \alpha S(p,f) - F \\
\text{s.t.} \quad & p \geq 0 \\
& 0 \leq f \leq \bar{f}.
\end{aligned}$$

Assuming that consumers have correct beliefs about the detection probability ($\phi = \pi$), we derive the following result.

Proposition 3. *Under Assumptions 1 and 2, (i) if* $\alpha < 1$*, the optimal price for paying consumers satisfies* $p^* > \pi f^*$*, and the optimal expected fine* πf^* *exceeds the unit cost* c *at an interior solution for* f *and may be below unit cost at a corner solution where* $f^* = \bar{f}$*; and (ii) if* $\alpha = 1$*, the welfare maximizing price and fine satisfy* $p^* = \pi f^* = c$ *at an interior solution for* f*.*

Proposition 3 shows that regular consumers pay more than payment evaders pay in expectation as long as profit has a higher relative weight than consumer surplus in the objective function ($\alpha < 1$). Specifically, the Lerner index is given by

$$\frac{p^* - c}{p^*} = \frac{1-\alpha}{\varepsilon} + \frac{\pi f^* - c}{p^*},$$

which shows that the price discrimination result in Proposition 1 naturally generalizes beyond profit maximization. As in the baseline model, it can be optimal for the firm to sustain losses on payment evaders when it is constrained by $\bar{f}$ in setting the optimal fine. Instead, under standard welfare maximization ($\alpha = 1$), price discrimination is not optimal and price-cost margins are compressed to zero on both demand segments ($p^* = \pi f^* = c$). Observe that there is a parallel to the theory of public law enforcement (Polinsky and Shavell 2007) under standard welfare maximization: all consumers with a valuation higher than the social cost are induced to consume the product, and the optimal fine is set accordingly at $f^* = \frac{c}{\pi}$.[12]

4.2 Endogenous Detection Probability

In line with the theory on public law enforcement, we now assume that the firm can influence the detection probability $\pi(e)$ and the cost of the detection technology $F(e)$ through its choice of the control effort e. Accordingly, we let consumer beliefs depend on effort. Specifically, we assume that $\phi = \pi(e)$. The firm then chooses the price p, the fine f, and the control effort e to solve

$$\begin{aligned}
\max_{p,f,e} \quad & \Omega(p,f,e) = (p-c)D(p,f) + (\pi(e)f - c)E(p,f) + \alpha S(p,f) - F(e) \\
\text{s.t.} \quad & p \geq 0 \\
& 0 \leq f \leq \bar{f} \\
& e \geq 0.
\end{aligned}$$

[12]In the context of public transportation, welfare maximization thus leads to "ridership maximization."

For simplicity, we assume that $\pi(e)$ is strictly concave with $\pi(0) = 0$ and $\pi(+\infty) = 1$ and that the effort cost, $F(e)$, is strictly convex with $F(0) = 0$. We derive the following result.

Proposition 4. *Under Assumptions 1 and 2, (i) if $\alpha < 1$, the optimal price for paying consumers satisfies $p^* > \pi(e^*)f^*$, and the optimal expected fine $\pi(e^*)f^*$ exceeds the unit cost c at an interior solution for f and may be below unit cost at a corner solution where $f^* = \overline{f}$; (ii) if $\alpha = 1$, the welfare maximizing price and expected fine satisfy $p^* = \pi(e^*)f^* = c$; (iii) the optimal effort e^* solves the first-order condition*

$$\pi'(e^*)[(p^* - c)D_\pi + (\pi(e^*)f^* - c)E_\pi + (1-\alpha)f^*E] - F'(e^*) \leq 0;$$

(iv) the comparative statics effects of an increase in a binding maximum fine $\overline{f}$ on $p^*(\overline{f})$ and $e^*(\overline{f})$ are ambiguous.

Proposition 4 shows that the price discrimination result carries over to the case with an endogenous detection probability. At an interior solution, the optimal effort satisfies the condition that the marginal revenue from regular consumers and payment evaders equals the marginal cost of implementing that effort level. The result also shows that the comparative statics effects of an increase in a binding $\overline{f}$ on the optimal price and effort are ambiguous. This follows from the fact that the sign of the cross-partial derivative Ω_{ef} is indeterminate. In order to work out clear-cut comparative statics (see, e.g., Vives 2000), we would need to put additional structure on D and X. It therefore remains an empirical question whether an increase in the binding maximum fine increases price and control effort.

4.3 Regulatory Capture

It is well known that regulatory agencies might be influenced to pursue the self-interests of the industries they oversee or follow the agenda of other interest groups (Laffont and Tirole 1993; Dal Bó 2006). Regulatory capture can therefore be viewed as a reasonable alternative to the setting in which the firm seeks to maximize a weighted sum of consumer and producer surplus.

To see how regulatory capture might affect our analysis, we consider a setting in which the regulator chooses the price p and the fine f to solve

$$\max_{p,f} \quad \Psi(p,f) = \Pi(p,f) + A(p,f)$$
$$\text{s.t. } p \geq 0$$
$$0 \leq f \leq \overline{f},$$

where $\Pi(p, f)$ is the firm's profit and $A(p, f)$ reflects the regulator's "political agenda" associated with capture. Note that this setting nests profit maximization $(A(p, f) = 0)$ and standard welfare maximization $(A(p, f) = S(p, f))$, respectively. To model the effect of regulatory capture on the price and fine, we impose the following assumption on the political agenda.

Assumption 3. *The regulator's political agenda satisfies* $-D(p, f) < A_p(p, f) \leq 0$ *and* $A_f(p, f) \geq 0$.

Assumption 3 reflects a preference for low prices and high fines. We next show that the price discrimination result emerges even under this unfavourable assumption.

Proposition 5. *Under Assumptions 1–3, (i) the regulated price* p^r *satisfies*

$$\frac{p^r - c}{p^r} = \frac{1}{\varepsilon}\left(1 + \frac{A_p}{D}\right) + \frac{\pi f^r - c}{p^r};$$

and (ii) the regulated expected fine πf^r *exceeds the unit cost* c *at an interior solution for* f *and may be below unit cost at a corner solution where* $f^r = \overline{f}$.

Proposition 5 shows that regulation does not protect paying consumers from price discrimination: regular consumers pay a higher regulated price than payment evaders pay in expectation ($p^r > \pi f^r$). It is worth noting that the regulator compresses the markup charged to regular consumers relative to the baseline model (Proposition 1) if the price has a negative impact on the political agenda. Finally, Proposition 5 shows that a captured regulator may or may not allow the firm to generate a profit from payment evasion (the captured regulator's ability to distort the regulated fine upward continues to be constrained by the legal framework, i.e., $f^r \leq \overline{f}$).

5 Evidence from Fare Dodging

This section complements our theoretical analysis with an empirical case study of fare dodging on the *Zurich Transport Network* (ZVV), one of Switzerland's largest public transport networks with more than 600 million passengers a year. We provide insights on firm decisions and quantify payment evasion.

5.1 Background

The ZVV is responsible for coordinating, marketing, and financing public transport in the Zurich metropolitan area. Its operations bring together more than 50 transport companies

Table 1: Maximum Admissible Fines for Fare Dodging.

	Before June 1, 2011	After June 1, 2011	Change in %
First offense	80	100	25.0
Second offense*	120	140	16.7
Three or more offenses*	150	170	13.3

Notes: The fines ("penalty fares") are relevant from June 1, 2009, through May 31, 2013, and stated in Swiss Francs (CHF). *Higher fines apply to violations within two years of settlement of the last offense.

that provide railroad, bus, tram, boat, and cable car services. About 60% of the ZVV's expenses are covered by ticket revenues, and the remainder is covered by government subsidies.[13]

Similar to our theoretical analysis in Section 4.2, the ZVV chooses the ticket prices, the fines for payment evasion, and the control effort to detect payment evaders. The key difference to the model is that there are multiple ticket prices (for single and multiple journeys, and for trips of different lengths) and multiple fines for fare dodging (for first-time and repeat offenders, respectively). The prices set by the ZVV are subject to public consultation and approved by the government. Since we observe neither the journeys that individuals make nor the prices that they pay, we focus on the lowest available ticket price, which was held fixed at 2.20 Swiss Francs (CHF) throughout the observation period.[14] The fines for payment evasion, in turn, are capped by maximum admissible fines set by the national industry association for public transport (*Verband öffentlicher Verkehr*, VöV). Table 1 lists these maximum admissible fines, which must reflect (a) the foregone revenue and (b) the cost caused by payment evaders (SWISS PASSENGER TRANSPORT ACT §20). Before June 1, 2011, the maximum fine for the first offense was CHF 80. For the second offense, the maximum fine was CHF 120. For the third and any subsequent offenses within two years, the maximum fine was CHF 150. After June 1, 2011, the maximum admissible fines were CHF 100, CHF 140, and CHF 170, respectively. It turns out that the ZVV exploits the scope of the legal system and charges the maximum admissible fines for fare dodging both before and after the change in fines. Information on the relevant fines is prominently posted at all stops, in the entry areas, and on the windows of all means of transport. Finally, the ZVV's choice of effort determines the detection probability faced by payment evaders.

[13]Detailed information about the ZVV is available at http://www.zvv.ch.

[14]Note that 1 Swiss Franc roughly corresponds to 1 US Dollar.

The public transport network is set up as an "open-access" system that allows passengers to board transport vehicles without prior ticket inspection. The ticket inspections are unannounced and random from the perspective of passengers. When ticket inspection agents board a vehicle, they require all passengers to present their ticket, which rules out statistical discrimination. Passengers who fail to present a valid ticket must prove their identity, are registered in the electronic data pool on detected payment evaders, and must pay a fine. In addition, the inspection agents record the number of passengers who are checked in ticket inspections.

5.2 Data

We combine data from three different sources. First, we use census data on transport and mobility to obtain the characteristics of the reference group of all passengers on the ZVV's transport network.[15] Second, we use passenger-level data from the ZVV's data pool, which provides information on all detected payment evaders. The data pool allows the ZVV to identify repeat offenders and construct the two-year period during which higher fines apply.[16] Third, we employ aggregate data compiled by the ZVV on the total number of passengers and the number of checked passengers, which cover the observation period from June 1, 2009, through May 31, 2013.

Table 2 provides descriptive statistics for the reference group that is composed of all passengers (labeled Census) and all payment evaders (labeled Evaders) detected during the first year of observation (from June 1, 2009, through, May 31, 2010) based on passenger-level data.[17] Fare dodging is clearly a relevant phenomenon: During the first year of observation, the ZVV collected an average fine of CHF 120 from more than 112,000 detected fare dodgers, thereby generating a revenue of more than CHF 13.4 million.[18] The descriptive statistics indicate that men and young adults are significantly overrepresented among detected payment evaders. These observations are consistent with previous studies of crime (DiIulio 1996) and shoplifting (Cox et al. 1990), which report

[15]The census, *Mikrozensus Mobilität und Verkehr 2010*, is a representative study compiled by the Swiss Federal Statistical Office (see http://www.bfs.admin.ch).

[16]Data privacy laws require the ZVV to delete the records of passengers who have no repeated offenses within two years.

[17]The choice of this period ensures that the selection process is plausibly unaffected by the change in maximum admissible fines.

[18]The average fine includes additional fees from other violations, including attempted escape from ticket inspection and using forged tickets. Such additional violations are committed by 1.1% of the detected payment evaders.

Table 2: Descriptive Statistics for the Passenger Groups.

	Comparison of Groups			Breakdown of Evaders by Number of Offenses			
Average values	Census	Evaders	p-value	1	2-3	4-7	8+
Men (in %)	48	57	0.00	55	63	73	75
Age in years	39	31	0.00	32	29	28	28
Amount in CHF	–	120	–	108	155	191	190
Other violations (in %)	–	1.1	–	1.1	1.2	1.4	0.6
Number of individuals	3,734	112,872	–	90,396	18,061	3,337	1,078

Notes: All individuals in the data set had a permanent address in Switzerland. The reference group (Census) consists of a representative sample of passengers, including evaders. The group of payment evaders (Evaders) consists of all evaders detected from June 1, 2009, through May 31, 2010. The p-value is determined from a two-sample t-test for mean differences between the groups. Repeat offenders: 1, 2-3, 4-7, and 8+ offenses by the same individual. Other violations is an indicator of whether payment evasion was associated with some other violation (including attempted escape from ticket inspection or using forged tickets).

a concentration of offenses among young men. In addition, the degree of overrepresentation is positively related to the number of offenses.

5.3 Industry Insights

We now provide the results of our case study of fare dodging based on aggregate data and relate them to our theoretical analysis.

Pricing. Price discrimination entails that paying consumers pay a higher ticket price than payment evaders pay in expectation. In order to compute the expected fines, we estimate the detection probability by the ratio of the number of checked passengers C to the total number of passengers $D+E$, that is, $\hat{\pi} = C/(D+E)$, and multiply the posted fines by the relevant detection probability to obtain the expected fines. Table 3 confirms that even the lowest available ticket price (CHF 2.20)—and thus any ticket price—exceeds the highest expected fine before and after the increase in $\overline{f}$ (CHF 2.07 and CHF 2.15, respectively). We conclude that the ZVV engages in second-degree price discrimination. Our theory suggests that this type of price discrimination is consistent with the maximization of profit, a weighted average of profit and consumer surplus, or regulatory capture. It is not consistent with the maximization of standard welfare, however, which requires that both price and expected fine equal marginal cost and thus excludes price discrimination.

Table 3: Industry Insights on Fare Dodging.

	Before June 1, 2011	After June 1, 2011	Change in %
Firm Decisions			
Lowest ticket price	2.20	2.20	–
Expected fine			
First offense	1.10	1.27	14.7
Second offense	1.66	1.77	7.0
Three or more offenses	2.07	2.15	4.0
Monthly Average Outcomes			
Checked passengers C	645,427	613,049	-5.0
Total passengers $D+E$	46,751,476	48,411,632	3.6
Detection probability $\hat{\pi}$	1.38%	1.27%	-8.3
Detected evaders $\tilde{E}$	8,539	9,169	7.4
Estimated evasion $\hat{E}$	618,507	724,024	17.1
Evasion rate $\hat{R}$	1.32%	1.50%	13.0

Notes: Prices and expected fines are stated in CHF. Monthly average outcomes are based on aggregate data for the respective two-year period.

Effort Choice. In addition to pricing, the ZVV chooses the control effort to detect payment evaders. Table 3 shows that the number of checked passengers C, which we use as a proxy for the unobservable control effort e, was reduced by 5% after the increase in the (binding) fines. This reduction in the number of checked passengers translates into a reduction of the estimated detection probability $\hat{\pi}$ by 8.3%. Thus, we find that the ZVV has reduced the costly control effort in exchange for higher monetary fines. This finding is in line with the theory on public law enforcement, which emphasizes that "society should employ the highest possible fine and a correspondingly low probability of detection in order to economize on enforcement expenditures" (Polinsky and Shavell 2007, p. 413).

It is worthwile to consider alternative explanations for the reduction in the number of checked passengers, such as an increase in the cost of control or a reduction in the number of personnel. To the best of our knowledge, the salaries of the control personnel remained stable. Similarly, although there is anecdotal evidence that ticket inspections were not always equally effective across time and transport companies, internal reports of the ZVV do not show a decrease in the number of hours spent on ticket inspections. It therefore seems unlikely that the number of checked passengers has fallen because of an increase in the cost of ticket inspections or a reduction in the number of workers who perform ticket inspections.

Quantifying Payment Evasion. Payment evasion is endogenously determined by the interplay of the choices made by the ZVV and by its passengers. In order to quantify payment evasion $\hat{E}$, we divide the number of detected payment evaders $\tilde{E}$ by the estimated detection probability $\hat{\pi}$, that is, $\hat{E} = \tilde{E}/\hat{\pi}$. Table 3 reports the estimated levels of payment evasion and the corresponding evasion rates expressed as a fraction of the total number of passengers, that is, $\hat{R} = \hat{E}/(D+E)$. We find that both the level of payment evasion and the rate of payment evasion are increasing during the time of observation.

We first want to make sense of the increase in the level of payment evasion. Our theoretical analysis suggests that the changes in the industry environment not only affect the firm's pricing and effort choice, but also the consumers' beliefs about the detection probability. Therefore, the observed change in payment evasion can be decomposed as

$$d\hat{E}(p,\overline{f};\hat{\pi},\hat{N}) = E_f(p,\overline{f})d\overline{f} + E_\pi(p,\overline{f})d\hat{\pi} + E_N(p,\overline{f})d\hat{N},$$

where $d\overline{f} > 0$, $d\hat{\pi} < 0$, and $d\hat{N} > 0$ denote the respective changes observed in the data (note that price does not have an impact as $dp = 0$). A higher fine f and a higher detection probability π have a stronger deterrence effect and reduce payment evasion accordingly, that is, $E_f < 0$ and $E_\pi < 0$. On the other hand, a larger market potential N (proxied by the total number of passengers) increases payment evasion, that is, $E_N > 0$. Thus, one possible explanation for the increase in payment evasion, $d\hat{E} > 0$, is that the positive impact from the reduction in the detection probability and the larger market potential outweighed the negative impact from the increase in fines. Put differently, in a growing market for public transportation, the ZVV's decision to rebalance the control effort and the monetary fines resulted in a higher level of payment evasion.

Next consider the observed increase in the rate of payment evasion, $d\hat{R} > 0$. Such an increase requires that the demand of consumers who evade payment grows more strongly than the demand of paying consumers. Our model suggests that such an increase in the evasion rate may result from a disproportionately high inflow of consumer types who are more inclined to evade payment.

6 Conclusion

We have analyzed how firms can deal with payment evasion using the purchase price and a fine imposed on detected payment evaders. In addition, we have provided empirical evidence on payment evasion using data from fare dodging on public transportation.

We have derived three key results from our theoretical analysis. First, the presence of payment evaders leads to a form of second-degree price discrimination in which the purchase price exceeds the expected fine for payment evasion. Second, the impact of an increase in binding maximum admissible fines on payment evasion is generally ambiguous, because such increases have a negative direct effect and a positive price-mediated effect on payment evasion. Third, the result on price discrimination generalizes naturally beyond the case of profit maximization.

The empirical case study of fare dodging on Zurich's transport network illustrates our theoretical analysis. First, we find that the transport operator does indeed engage in price discrimination: the prices paid by regular consumers are higher than the expected fines. Second, we document that the transport operator reduced the costly control effort in exchange for higher monetary fines. Third, we use our theory to provide an explanation for the increase in the level and the of rate payment evasion following the increase in the maximum admissible fines.

Our analysis suggests several avenues for future research. First, one could generalize our analysis to a fully dynamic setting in which consumers repeatedly decide whether to evade payment. Second, one could extend the analysis to allow for competition among firms to study the role of payment evasion for nonprice competition. Third, it would be interesting to further examine the extent to which the logic of our analysis applies to tax evasion (i.e., whether higher penalties on tax evasion help sustain higher tax rates). We hope to address these issues in future research.

Appendix

Proof of Lemma 1. From (1), the demand of paying consumers is $D = N[1 - G(\overline{\theta})]$. This demand decreases in price p provided that

$$D_p(p, f) = -Ng(\overline{\theta}(p, f))\frac{\partial\overline{\theta}(p, f)}{\partial p} < 0.$$

Applying the implicit function theorem to the indifference condition $v_P(p;\overline{\theta}) = v_E(f;\overline{\theta})$, which defines $\overline{\theta}$, yields

$$\frac{\partial\overline{\theta}(p, f)}{\partial p} = -\frac{\frac{\partial}{\partial p}v_P(p;\overline{\theta})}{\frac{\partial}{\partial\theta}(v_P(p;\overline{\theta}) - v_E(f;\overline{\theta}))}. \tag{A.1}$$

Invoking Assumption 1, the numerator on the right-hand side of (A.1) is equal to -1 and the denominator is strictly positive. Consequently, since $g(\theta) > 0$ for all θ, the demand of paying consumers satisfies $D_p(p, f) < 0$. Next, the demand of paying consumers increases in the fine f provided that

$$D_f(p, f) = -Ng(\overline{\theta}(p, f))\frac{\partial\overline{\theta}(p, f)}{\partial f} > 0$$

where

$$\frac{\partial\overline{\theta}(p,f)}{\partial f} = \frac{\frac{\partial}{\partial f}v_E(f;\overline{\theta}))}{\frac{\partial}{\partial\theta}(v_P(p;\overline{\theta}) - v_E(f;\overline{\theta}))} < 0,$$

which is a negative expression by Assumption 1. Hence, the demand of paying consumers satisfies $D_f(p,f) > 0$.

From (2), demand for the outside option is $X = N[G(\underline{\theta})]$. This demand increases in the fine f provided that

$$X'(f) = Ng(\underline{\theta}(f))\frac{\partial\underline{\theta}(f)}{\partial f} > 0 \tag{A.2}$$

where

$$\frac{\partial\underline{\theta}(f)}{\partial f} = -\frac{\frac{\partial}{\partial f}v_E(f;\underline{\theta})}{\frac{\partial}{\partial\theta}v_E(f;\underline{\theta})} > 0,$$

which is a positive expression by Assumption 1. Thus, the demand for the outside option satisfies $X'(f) > 0$. $\square$

Proof of Proposition 1. (i) By Assumption 1, $D > 0$, and by Lemma 1, $D_p < 0$. Then, if $p^m \leq \pi f^m$, (3) leads to a contradiction since $\lambda_1 \geq 0$. Hence, at the optimum, we must have that $p^m > \pi f^m$ and $\lambda_1 = 0$. Consequently, (3) can be rearranged as

$$\frac{p^m - c}{p^m} = \frac{1}{\varepsilon} + \frac{\pi f^m - c}{p^m}.$$

(ii) By Lemma 1, $D_f > 0$ and $X' > 0$. Now suppose that $f^m = 0$ and thus that $\lambda_3 = 0$. Then, (4) leads to a contradiction, implying that f^m is strictly positive. Therefore, at the optimum, either $\lambda_2 = 0$ (corner solution) or both $\lambda_2 = 0$ and $\lambda_3 = 0$ (interior solution). Now, if $f^m = \overline{f}$ and thus $\lambda_2 = 0$, (4) can be written as

$$\begin{aligned}(p^m - \pi\overline{f})D_f(p^m,\overline{f}) + \pi(N - D(p^m,\overline{f}) - X(\overline{f}))& \\ -(\pi\overline{f} - c)X'(\overline{f}) &= \lambda_3 \geq 0.\end{aligned}$$

A corner solution $f^m = \overline{f}$ exists if

$$(\pi\overline{f} - c)X'(\overline{f}) \leq (p^m - \pi\overline{f})D_f(p^m,\overline{f}) + \pi(N - D(p^m,\overline{f}) - X(\overline{f})),$$

that is, if the marginal cost of raising f, $(\pi\overline{f} - c)X'(\overline{f})$, is less than the corresponding marginal benefit, $(p^m - \pi\overline{f})D_f(p^m,\overline{f}) + \pi(N - D(p^m,\overline{f}) - X(\overline{f}))$. Since $p^m > \pi f^m$, the marginal benefit is strictly positive. Therefore, at a corner solution, the firm may generate a profit or sustain a loss from payment evasion. An interior solution $f^m \in (0,\overline{f})$ exists if

$$(\pi f^m - c)X'(f^m) = (p^m - \pi f^m)D_f(p^m,f^m) + \pi(N - D(p^m,f^m) - X(f^m)).$$

Since the marginal benefit of raising f is strictly positive, we must have that $\pi f^m > c$. Thus, at an interior solution, the firm generates a strictly positive profit from payment evaders. $\square$

Proof of Proposition 2. If $f^m = \overline{f}$, $p^m(\overline{f})$ is determined by (3). (i) The comparative statics effect of a change in $\overline{f}$ on the optimal price $p^m(\overline{f})$ is readily determined by applying the implicit function theorem to the first-order condition in (3), evaluated at $\overline{f}$:

$$\frac{dp^m(\overline{f})}{df} = -\frac{D_f + (p^m - \pi\overline{f})D_{pf} - \pi D_p}{2D_p + (p^m - \pi f)D_{pp}}. \tag{A.3}$$

From Proposition 1, we have that $p^m - \pi\overline{f} > 0$. Clearly, the numerator of (A.3) is positive using the properties of D, and the denominator is negative by the concavity of the objective function. Hence, $p^m(\overline{f})$ increases in $\overline{f}$ under the sufficient condition stated in the proposition. (ii) At the optimum, payment evasion is given by $E^m(\overline{f}) \equiv E(p^m(\overline{f}), \overline{f})$. Totally differentiating this expression produces

$$\frac{dE^m(\overline{f})}{df} = E_p \frac{dp^m(\overline{f})}{df} + E_f.$$

Lemma 1 and part (i) of Proposition 2 immediately imply that the impact of $\overline{f}$ on payment evasion is generally ambiguous. (iii) From the fundamental theorem of calculus, the overall change in payment evasion can be decomposed as

$$\begin{aligned} E(p_0^m, \overline{f}_1) - E(p_0^m, \overline{f}_0) &= \int_{\overline{f}_0}^{\overline{f}_1} E_f(p_0^m, f)df \\ &= -\left[\int_{\overline{f}_0}^{\overline{f}_1} D_f(p_0^m, f)df + \int_{\overline{f}_0}^{\overline{f}_1} X'(f)df\right] \\ &= N\left[\int_{\overline{f}_0}^{\overline{f}_1} g(\overline{\theta})\frac{\partial\overline{\theta}}{\partial f}df - \int_{\overline{f}_0}^{\overline{f}_1} g(\underline{\theta})\frac{\partial\underline{\theta}}{\partial f}df\right], \end{aligned} \tag{A.4}$$

where the second equality follows from Definition 1 and the third equality from (1) and (2). The result is obtained by integration by substitution using the definition of $\underline{\theta}(f)$ and $\overline{\theta}(p, f)$ in Assumption 1. □

Proof of Corollary 1. (i) The firm chooses the price and fine so as to

$$\max_{p,f} \quad \Pi(p, f) = (p-c)\left(1 - \frac{p - \pi f - k}{s_P - s_E}\right) + (\pi f - c)\left(\frac{ps_E - (\pi f + k)s_P}{(s_P - s_E)s_E}\right)$$

subject to the constraints $p \geq 0$ and $0 \leq f \leq \overline{f}$. Partially differentiating the profit function with respect to f yields

$$\Pi_f(p, f) = \frac{\pi(2(ps_E - \pi f s_P) + c(s_P - s_E) - ks_P)}{(s_P - s_E)s_E},$$

which is strictly positive for $k < \overline{k}$. This implies that there is no interior solution for f, and the profit-maximizing price follows from Proposition 1. (ii) The result follows by inspection of p^m. (iii) Payment evasion results by substitution, and $E^m \geq 0$ as long as $k < \frac{(s_P - s_E)(s_E - 2\pi\overline{f})}{2s_P - s_E}$ (the upper bound for k expresses $\overline{k}$ in terms of the model parameters). Inspection of E^m shows that it decreases in $\overline{f}$. □

Proof of Proposition 3. We first establish that the partial derivatives of consumer surplus are linked to demands—a standard property (Armstrong and Vickers 2015). We have the following result.

Lemma A1. *Under Assumption 1,*

$$S_p(p,f) = -D(p,f) \qquad \textit{and} \qquad S_f(p,f) = -\phi E(p,f).$$

Proof. Using Leibniz's rule, differentiating consumer surplus with respect to p yields:

$$\begin{aligned} S_p(p,f) &= N\int_{\bar{\theta}(p,f)}^{\infty} \frac{\partial v_P(p;\theta)}{\partial p} g(\theta)d\theta - N\frac{\partial\bar{\theta}}{\partial p}v_P(p;\bar{\theta})g(\bar{\theta}) + N\frac{\partial\bar{\theta}}{\partial p}v_E(p;\bar{\theta})g(\bar{\theta}) \\ &= N\int_{\bar{\theta}(p,f)}^{\infty} \frac{\partial v_P(p;\theta)}{\partial p} g(\theta)d\theta - N\frac{\partial\bar{\theta}}{\partial p}\left[v_P(p;\bar{\theta}) - v_E(f;\bar{\theta})\right]g(\bar{\theta}) \\ &= N\int_{\bar{\theta}(p,f)}^{\infty} \frac{\partial v_P(p;\theta)}{\partial p} g(\theta)d\theta, \end{aligned}$$

where the last equality uses that $v_P(p;\bar{\theta}) = v_E(f;\bar{\theta})$ by Assumption 1. Since $v_P(p;\theta)$ is quasi-linear in price p, we have that $\frac{\partial v_P(p;\theta)}{\partial p} = -1$ and thus that

$$S_p(p,f) = -N\int_{\bar{\theta}(p,f)}^{\infty} g(\theta)d\theta = -D(p,f). \tag{A.5}$$

Similarly, differentiating consumer surplus with respect to f yields:

$$\begin{aligned} S_f(p,f) &= -N\frac{\partial\bar{\theta}}{\partial f}v_P(p;\bar{\theta})g(\bar{\theta}) + N\int_{\underline{\theta}(f)}^{\bar{\theta}(p,f)} \frac{\partial v_E(f;\theta)}{\partial f} g(\theta)d\theta \\ &\quad + N\frac{\partial\bar{\theta}}{\partial f}v_E(f;\bar{\theta})g(\bar{\theta}) - N\frac{\partial\underline{\theta}}{\partial f}v_E(f;\underline{\theta})g(\underline{\theta}) \\ &= N\int_{\underline{\theta}(f)}^{\bar{\theta}(p,f)} \frac{\partial v_E(f;\theta)}{\partial f} g(\theta)d\theta. \end{aligned} \tag{A.6}$$

The last equality holds as the first and the third term in (A.6) cancel each other out, and because $v_E(f;\underline{\theta}) = 0$ by construction. Since $v_E(f;\theta)$ is quasi-linear in the expected fine ϕf, we have that $\frac{\partial v_E(f;\theta)}{\partial f} = -\phi$ and thus that

$$S_f(p,f) = -\phi N\int_{\underline{\theta}(f)}^{\bar{\theta}(p,f)} g(\theta)d\theta = -\phi E(p,f).$$

□

Next, we establish Proposition 3.

Proof. The necessary and sufficient Kuhn-Tucker conditions for a constrained maximum of Ω are

$$\begin{aligned} D(p^*,f^*)+(p^*-c)D_p(p^*,f^*)+(\pi f^*-c)E_p(p^*,f^*)+\alpha S_p(p^*,f^*) &= -\lambda_1 \\ (p^*-c)D_f(p^*,f^*)+\pi E(p^*,f^*)+(\pi f^*-c)E_f(p^*,f^*)+\alpha S_f(p^*,f^*) &= -\lambda_2+\lambda_3 \\ \lambda_1 p^*=0, \quad \lambda_2 f^*=0, \quad \text{and} \quad \lambda_3(f^*-\overline{f}) &= 0. \end{aligned}$$

Using Lemma A1, the first-order conditions for p and f can be rearranged as:

$$(1-\alpha)D(p^*,f^*)+(p^*-\pi f^*)D_p(p^*,f^*) = -\lambda_1 \tag{A.7}$$

$$-(\pi f^*-c)X'(f^*)+(\pi-\alpha\phi)E(p^*,f^*) = -\lambda_2+\lambda_3. \tag{A.8}$$

Further, since consumers have correct beliefs about the detection probability ($\phi=\pi$), (A.8) can be simplified to

$$-(\pi f^*-c)X'(f^*)+(1-\alpha)\pi E(p^*,f^*) = -\lambda_2+\lambda_3. \tag{A.9}$$

To determine the optimal price, suppose that $p^*=0$ and $\lambda_1>0$. Then we have a contradiction as $D>0$ and $D_p<0$. Now consider an interior solution where $p^*>0$ and hence $\lambda_1=0$. For $\alpha<1$ we must have that $p^*>\pi f^*$. Instead, for $\alpha=1$, the only admissible solution is $p^*=\pi f^*$. At an interior solution (A.7) can be rewritten as

$$\frac{p^*-c}{p^*}=\frac{1-\alpha}{\varepsilon}+\frac{\pi f^*-c}{p^*}.$$

To determine the optimal fine, suppose first that $f^*=0$ and $\lambda_3=0$. Then we have a contradiction. Instead, suppose that $f^*=\overline{f}$ and $\lambda_2=0$. This yields

$$-(\pi\overline{f}-c)X'(\overline{f})+(1-\alpha)\pi E(p^*,\overline{f})=\lambda_3\geq 0$$

and a corner solution exists if

$$(\pi\overline{f}-c)X'(\overline{f})\leq(1-\alpha)\pi E(p^*,\overline{f}).$$

An interior solution $f^*\in(0,\overline{f})$ exists if

$$(\pi f^*-c)X'(f^*)=(1-\alpha)\pi E(p^*,f^*).$$

Therefore, for $\alpha<1$, we must have that $\pi f^*>c$ at an interior solution and it is possible that $\pi\overline{f}<c$ at a corner solution. Instead, for $\alpha=1$, the only admissible solution is $\pi f^*=c$. □

Proof of Proposition 4. We first establish how the partial derivative of consumer surplus

$$S(p,f,\pi(e))=N\int_{\overline{\theta}(p,f,\pi(e))}^{\infty}v_P(p,\theta)g(\theta)d\theta+N\int_{\underline{\theta}(f,\pi(e))}^{\overline{\theta}(p,f,\pi(e))}v_E(f,\theta,\pi(e))g(\theta)d\theta$$

with respect to effort e is linked to payment evasion. We have the following result.

Lemma A2. *Under Assumption 1,* $S_e(p,f,\pi(e)) = -\pi'(e) f E(p,f,\pi(e))$.

Proof. Using Leibniz's rule, differentiating consumer surplus with respect to e yields:

$$\begin{aligned} S_e(p,f,\pi(e)) &= -N\frac{\partial\bar{\theta}}{\partial\pi}\pi'(e)v_P(p,\bar{\theta})g(\bar{\theta}) + N\int_{\underline{\theta}(f,\pi(e))}^{\bar{\theta}(p,f,\pi(e))} \frac{\partial v_E(f,\theta,\pi(e))}{\partial\pi}\pi'(e)g(\theta)d(\theta) \\ &\quad + N\frac{\partial\bar{\theta}}{\partial\pi}\pi'(e)v_E(f,\bar{\theta},\pi(e))g(\bar{\theta}) - N\frac{\partial\underline{\theta}}{\partial\pi}\pi'(e)v_E(f,\underline{\theta},\pi(e))g(\underline{\theta}) \qquad \text{(A.10)} \\ &= N\int_{\underline{\theta}(f,\pi(e))}^{\bar{\theta}(p,f,\pi(e))} \frac{\partial v_E(f,\theta,\pi(e))}{\partial\pi}\pi'(e)g(\theta)d(\theta), \end{aligned}$$

where the last equality holds as the first and the third term in (A.10) cancel each other out and because $v_E(f,\underline{\theta},\pi(e)) = 0$ by construction. Since $v_E(f,\theta,\pi(e))$ is quasi-linear in the expected fine $\pi(e)f$, we have that $\frac{\partial v_E(f,\theta,\pi(e))}{\partial\pi} = -f$ and thus that

$$S_e(p,f,\pi(e)) = -\pi'(e) f N\int_{\underline{\theta}(f,\pi(e))}^{\bar{\theta}(p,f,\pi(e))} g(\theta)d(\theta) = -\pi'(e) f E(p,f,\pi(e)).$$

□

Next, we establish Proposition 4. To simplify exposition, we suppress the arguments of the respective functions whenever possible.

Proof. The necessary and sufficient Kuhn-Tucker conditions for a constrained maximum of Ω are given by

$$\begin{aligned} D + (p^*-c)D_p + (\pi(e^*)f^*-c)E_p + \alpha S_p &= -\lambda_1 \\ (p^*-c)D_f + \pi(e^*)E + (\pi(e^*)f^*-c)E_f + \alpha S_f &= -\lambda_2 + \lambda_3 \\ \pi'(e^*)[(p^*-c)D_\pi + (\pi(e^*)f^*-c)E_\pi + f^*E] + \alpha S_e - F'(e^*) &= -\lambda_4 \qquad \text{(A.11)} \\ \lambda_1 p^* = 0, \quad \lambda_2 f^* = 0, \quad \lambda_3(f^*-\bar{f}) = 0, \quad \text{and} \quad \lambda_4 e^* &= 0. \end{aligned}$$

Using Lemma A1, the first-order conditions for p and f can be rearranged as:

$$\begin{aligned} (1-\alpha)D + (p^*-\pi(e^*)f^*)D_p &= -\lambda_1 \\ (p^*-\pi(e^*)f^*)D_f - (\pi(e^*)f^*-c)X'(f^*) + (1-\alpha)\pi(e^*)E &= -\lambda_2 + \lambda_3. \end{aligned}$$

To determine the optimal price, suppose that $p^* = 0$ and $\lambda_1 > 0$. Then we have a contradiction as $D > 0$ and $D_p < 0$. Now consider an interior solution where $p^* > 0$ and hence $\lambda_1 = 0$. For $\alpha < 1$ we must have that $p^* > \pi(e^*)f^*$. Instead, for $\alpha = 1$, the only admissible solution is $p^* = \pi(e^*)f^*$.

To determine the optimal fine, suppose first that $f^* = 0$ and $\lambda_3 = 0$. This yields a contradiction. Instead, suppose that $f^* = \bar{f}$ and $\lambda_2 = 0$. This yields

$$(p^*-\pi(e^*)\bar{f})D_f(p^*,\bar{f}) - (\pi(e^*)\bar{f}-c)X'(\bar{f}) + (1-\alpha)\pi(e^*)E(p^*,\bar{f}) \geq 0$$

and a corner solution exists if

$$(\pi(e^*)\overline{f}-c)X'(\overline{f}) \le (p^*-\pi(e^*)\overline{f})D_f(p^*,\overline{f})+(1-\alpha)\pi(e^*)E(p^*,\overline{f}).$$

An interior solution $f^* \in (0,\overline{f})$ exists if

$$(\pi(e^*)f^*-c)X'(f^*) = (p^*-\pi(e^*)f^*)D_f(p^*,f^*)+(1-\alpha)\pi(e^*)E(p^*,f^*).$$

Therefore, for $\alpha < 1$, we must have that $\pi(e^*)f^* > c$ at an interior solution and it is possible that $\pi(e^*)\overline{f} < c$ at a corner solution for f. Instead, for $\alpha = 1$, the only admissible solution is $\pi(e^*)f^* = c$.

The optimal effort e^* is a solution to (A.11), where $\lambda_4 = 0$ (interior solution) or $\lambda_4 > 0$ (corner solution). Using Lemma A2, this first-order condition can be rearranged as:

$$\pi'(e^*)[(p^*-c)D_\pi+(\pi(e^*)f^*-c)E_\pi+(1-\alpha)f^*E]-F'(e^*) \le 0.$$

The comparative statics effects of an increase in $\overline{f}$ are ambiguous, because the sign of the cross-partial derivative

$$\Omega_{ef} = \pi'(e)\left[(p-c)D_{\pi f}+\pi(e)E_\pi+(\pi(e)f-c)E_{\pi f}+(1-\alpha)fE_f(1-1/\varepsilon_f)\right],$$

where $\varepsilon_f \equiv -\frac{fE_f}{E}$ denotes the elasticity of evasion with respect to fine, is indeterminate. $\square$

Proof of Proposition 5. The necessary and sufficient Kuhn-Tucker conditions for a constrained maximum of Ψ are:

$$\begin{aligned} D(p^r,f^r)+(p^r-\pi f^r)D_p(p^r,f^r)+A_p(p^r,f^r) &= -\lambda_1 \qquad \text{(A.12)} \\ (p^r-\pi f^r)D_f(p^r,f^r)-(\pi f^r-c)X'(f^r)+\pi E(p^r,f^r)+A_f(p^r,f^r) &= -\lambda_2+\lambda_3 \\ \lambda_1 p^r = 0, \quad \lambda_2 f^r = 0, \quad \text{and} \quad \lambda_3(f^r-\overline{f}) &= 0. \end{aligned}$$

(i) To determine the regulated price, suppose that $p^r = 0$ and $\lambda_1 > 0$. Then we have a contradiction as $D > 0$, $D_p < 0$, and $-D < A_p \le 0$ by assumption. At an interior solution where $p^r > 0$ and hence $\lambda_1 = 0$, we must have that $p^r > \pi f^r$, and (A.12) can be rearranged as

$$\frac{p^r-c}{p^r} = \frac{1}{\varepsilon}\left(1+\frac{A_p}{D}\right)+\frac{\pi f^r-c}{p^r}.$$

(ii) To determine the optimal fine, suppose first that $f^r = 0$ and $\lambda_3 = 0$. Then we have a contradiction as $D_f > 0$, $X' > 0$, $E \ge 0$, and $A_f \ge 0$ by assumption. Instead, suppose that $f^r = \overline{f}$ and $\lambda_2 = 0$. This yields

$$(p^r-\pi\overline{f})D_f(p^r,\overline{f})-(\pi\overline{f}-c)X'(\overline{f})+\pi E(p^r,\overline{f})+A_f(p^r,f^r) \ge 0,$$

and a corner solution exists if

$$(\pi\overline{f}-c)X'(\overline{f}) \le (p^r-\pi\overline{f})D_f(p^r,\overline{f})+\pi E(p^r,\overline{f})+A_f(p^r,\overline{f}).$$

An interior solution $f^r \in (0, \overline{f})$ exists if

$$(\pi f^r - c)X'(f^r) = (p^r - \pi f^r)D_f(p^r, f^r) + \pi E(p^r, f^r) + A_f(p^r, f^r).$$

Therefore, we must have that $\pi f^r > c$ at an interior solution. At a corner solution it is possible that $\pi \overline{f} < c$. □

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