Privacy, Driving Data and Automobile Insurance: An Economic Analysis

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Abstract

With new technologies that enable insurers to electronically monitor vehicles and drivers, insurers should be able to price automobile insurance more accurately, creating individualized prices for consumers. The welfare effects of lower prices are straightforward, but we also consider that consumers have heterogeneous valuations of privacy that they may lose if they adopt the monitoring technologies. We examine the voluntary market adoption of these monitoring technologies and its effect on equilibrium prices and welfare. We find a welfare effect equal to the loss in privacy, but conclude that the overall effect is ambiguous without considering moral hazard.

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Introduction

Event-data-recorders (EDRs) and telematics technology including GPS units (we simply refer to them collectively as EDRs) provide a means for automobile insurance companies to discover efficient estimates of the expected losses that automobile drivers will incur. Instead of solely relying on less refined rating variables such as age, gender, and marital status, insurers can use EDR technologies to improve their estimates.

These technologies may also compromise privacy in quite important ways, since they provide potentially comprehensive information not only on *how* individuals drive their vehicles, but also *where* and *when*. Not everyone values this loss of privacy the same, creating some interesting trade-offs which this paper explores.

EDRs are capable of generating, transmitting, analyzing, and storing sensitive data relating to the driving habits (an indicator of expected loss) of the individual automobile driver. EDRs provide data that can be a powerful predictor of the frequency and severity of automobile accidents. Without them, insurance firms must rely on less refined estimates of expected losses which are based on age, gender, and other characteristics. With EDRs, insurers can have access to extremely good information about the driving characteristics of insured drivers.

In the United States, Progressive Casualty Insurance Company instituted a voluntary program in 2004 in which the company gives drivers an EDR system. Users may receive a reduction in their insurance premium "based on when, how much and how fast they drive."[2] EDRs can also be used to inform the insurer of where the driver goes. In the United Kingdom,

[2] James Warden, "North Dakota, other states debate privacy safeguards on vehicle black boxes." Associated Press Archive, Fortwayne.com, March 25, 2005.

Norwich Union offers a program for young drivers which prices their insurance "based on how frequently and where they drive."[3] Users who drive at less congested – and therefore less dangerous times – pay lower insurance premiums.

The privacy ramifications of such technology are considerable. Data from EDRs has been used in court to determine liability in car accidents[4], for surveillance by police[5], and by car rental agencies to determine supplementary charges[6], as well as by insurers. The same technologies are being marketed to parents, who can use EDR to "tell whether teenagers are driving recklessly, whether they're wearing seat belts and whether they are just going to the library as they promised."[7] Adopting EDR, particularly for the purpose of demonstrating that a driver is "safe" through identifying when and where a car is driven, automatically creates intrusions into privacy which may not be desirable for some individuals. An insurer who knows where a car has been driven (for the purposes of determining an insurance premium) also has the ability to determine whether it has been driven repeatedly through a red-light district, for example. Thus an important feature of the data available to insurers through EDR and associated technologies is that it reveals much more about the driver than just the level of risks being insured.

Stigler (1981) points out that an individual will be willing to give up privacy – that is, to reveal personal information – when it is efficient to do so. For example, an individual may wish to establish a credit record to obtain a lower interest rate. Posner (1981) observes that increased privacy tends to reduce efficiency in transacting, since it forces reliance on inferior sources of

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[3] Daniel Thomas, "Norwich Union offers 'pay-as-you-drive' insurance." *Computing*, 27 January 2005.
[4] See Green and McClafferty (2004), Appendix III, for many examples of court cases in which EDR data has figured prominently.
[5] The Company v. USA, US Court of Appeals for the Ninth Circuit, No. 02-15635, November 18, 2005.
[6] American Car Rental, Inc,. v. Commissioner of Consumer Protection, Connecticut Supreme Court, 273 Conn. 296 (2005).
[7] Michelle Higgins, "A Back-Seat Driver for your Teen's Car." *Wall Street Journal*, 23 February 2005.

information. However, if privacy itself is a good, as discussed by Hirshleifer (1981) and Murphy (1996), then giving it up creates a loss. Of course, the valuation of privacy by individuals is not likely to be similar. Some people value it highly and guard it jealously, and some may have much lighter concerns about revealing personal information (Archer [1980], Culnan [1995], and Nowak and Phelps [1992]). Our analysis therefore includes a heterogeneously-valued loss of privacy for drivers who adopt EDR in line with Hui and Png (2006) who assert that consumers do value privacy and that they value it differently.

Filipova and Welzel (2005) investigate adverse selection, moral hazard and privacy with EDR-generated information which is accessed after an accident and provides high or low indemnity based on the revealed risk-type of the driver or the revealed effort level of the driver. In their scenario, the introduction of EDR technology enhances welfare unless there is initial cross-subsidization of risks. Our analysis differs in a number of respects, most notably in the modeling and conception of privacy.

Strauss and Hollis (2007) have analyzed the introduction of EDR technology if only one firm has access to the technology, and shown, in the absence of privacy concerns, that the welfare effect depends on whether competitive insurers are able to separate consumers through a menu of contracts. The result from Strauss and Hollis (2007) differs from that of Crocker and Snow (1986) because Crocker and Snow assume that all firms are symmetrically informed.

This paper follows the same reasoning as Strauss and Hollis (2007) but differs in three respects: we incorporate privacy, consumers know their risk-type[8], and we allow for the competitive use of EDR technology (i.e. we allow for symmetric information across insurers). The welfare effects, however, still depend on whether insurers can pool or separate consumers.

Our analysis offers two possible scenarios: consumers are required to have full insurance, or they may purchase partial insurance. Given a requirement to have full insurance, consumers have no way of signaling their risk-type, and so in the absence of EDR technologies, all consumers are pooled. Analyzing this situation allows us to focus on the interaction between insurance premiums and privacy. We also believe that this approach of examining the two extremes is valuable since reality likely lies somewhere in-between. In many situations, there are regulations which limit the extent to which consumers can use partial insurance to signal their type (as illustrated in Tables 1 and 2).

The typical minimum automobile insurance regulation (which varies from state to state and province to province) requires consumers to have a minimum amount of third-party liability insurance while some require mandatory no-fault accident-benefits coverage as well (primarily in Canada). Table 1 shows summary statistics for minimum automobile insurance requirements in the US as of 2007 for those states that had minimum automobile insurance requirements. Table 2 shows summary statistics for Canada.

[8] Note that if we assume that consumers do not know their risk type and that they are not required to purchase full insurance, we end up with the same result as that examined here in the model with full insurance, if consumers experiment with new technologies.

Table 1, Summary Statistics of US Automobile Insurance Third-Party-Liability Minimums by State, US $

	B.I./person	B.I./Total	P.D.
Mean	$23,098	$46,333	$14,620
Std. Dev.	$7,401	$14,939	$6,912
Min.	$10,000	$20,000	$5,000
Max	$50,000	$100,000	$25,000
Obs.	46	45	46

Retrieved from: http://www.dmv.org/ on November 5, 2007
B.I.=Bodily Injury, P.D.=Property Damage

Table 2, Summary Statistics of Canadian Automobile Insurance Minimum Requirements by Province, CDN $

	Min. Liability	Total A.B.	A.B./ Person
Alberta	$200,000	$50,000	n/a
British Columbia	$200,000	n/a	$150,000
Manitoba	$200,000	no limit	no limit
New Brunswick	$200,000	n/a	$50,000
New Found Land and Labrador	$200,000	n/a	n/a
Nova Scotia	$500,000	n/a	$25,000
Ontario	$200,000	n/a	$100,000
Prince Edward Island	$200,000	n/a	$25,000
Quebec	$50,000	n/a	n/a
Saskatchewan	$200,000	n/a	$5,502,000

Retrieved from: http://www.ibc.ca/en/Car_Insurance and http://www.saaq.gouv.qc.ca/en/index.php on November 5, 2007.
Min. Liability=minimum total third party liability insurance coverage required
A.B. = Accident Benefits (no fault insurance coverage akin to personal injury protection in the US). Saskatchewan also mandatorily requires collision and comprehensive coverage with a $700 deductible.

The two requirements of minimum insurance and mandatory participation in no-fault accident-benefits coverage are restrictions that are akin to requiring “full insurance.” By restricting the ability of the consumer to choose lower levels of third-party coverage and lower levels of no-fault accident-benefits coverage, the regulator limits the ability of the consumer to signal her risk-type to the insurer through partial insurance purchasing. While these minimum restrictions would not bind on all consumers, we suspect it likely that they bind on some. We analyze those situations here.

A Model with Full Insurance

Risk-averse consumers purchase insurance so as to alter their pattern of income across states of the world. Each consumer has a unique probability p_i of having an accident. For simplicity, we normalize the cost of an accident to equal one. The expected loss is then the probability of an accident. Let W_1 denote the consumer's wealth if there is no accident and W_2 his wealth if there is an accident. Let $\Pi \geq 0$ be an endowment of privacy that is equal across all individuals. EDR technology perfectly reveals the risk of the consumer to the insurer, but at a cost of less privacy. Let π be the amount of privacy that individuals must give-up in order to use EDR technology, $0 < \pi < \Pi$. Let $\beta_i \geq 0$ be an individual's valuation of privacy; privacy valuations are heterogeneous whereas the "quantities" of privacy endowed, and lost through EDR technology, are homogenous.[9] The consumer's expected utility (equation(1.1)) is then the standard expected utility function plus additional terms for the valuations of privacy.

$$U(p_i, W_1, W_2, \beta_i) = (1 - p_i)u(W_1) + p_i u(W_2) + \beta_i \Pi - \beta_i \pi \tag{1.1}$$

[9] Note that $U(\cdot)$ is a function of β_i and not Π or π. If a consumer does not choose EDR technology, $\pi = 0$.

Equation (1.1) is normally behaved so that the utility of wealth in both states of the world is increasing with wealth and the marginal utility is decreasing with wealth. The utility from privacy is increasing in privacy and the privacy valuation.

Every consumer is indifferent between states of the world because of the full insurance requirement. Let α_i be the cost of insurance for individual *i*. Let $\tilde{W}_i = W_1 - \alpha_i$ be the consumer's wealth in all states of the world once fully insured. Because each consumer receives full insurance and is indifferent between states of the world, the consumer's expected utility function in equation (1.1) can be rewritten as it is in equation (1.2) since the probabilities across states of the world must sum to one.

$$\begin{aligned} U(p_i, \tilde{W}, \beta_i) &= (1 - p_i)u(\tilde{W}_i) + p_i u(\tilde{W}_i) + \beta_i \Pi - \beta_i \pi \\ &= u(\tilde{W}_i) + \beta_i \Pi - \beta_i \pi \\ &= u(W_1 - \alpha_i) + \beta_i \Pi - \beta_i \pi \end{aligned} \tag{1.2}$$

Notice that the risk of an accident does not now directly enter the utility function since all consumers have full insurance. It is straightforward to see that utility-maximizing consumers will trade their privacy for gains in wealth (through a reduction in insurance prices α_i) when it is in their interest to do so.

In addition to that, it is also interesting to think about the externality that the consumers who adopt EDR (and trade privacy for lower prices) will have on the consumers who do not adopt EDR. Indeed, we will show that the consumers who are most likely to adopt EDR are those with relatively low risk; as they accept EDR and remove themselves from the pool, the prices that the remaining pooled consumers must pay will rise.

We assume that p_i and β_i have joint distribution $F(p_i, \beta_i)$ and we make no particular assumptions over this distribution.

The insurance premium α_i paid by the consumer depends on whether the consumer adopts EDR technology or not. In a competitive market in the absence of EDR technology, the pooled premium for the group is $\alpha_p^1 \equiv \int_0^\infty \int_0^1 p_i f(p_i, \beta_i) dp_i d\beta_i$ where each consumer has an expected loss of p_i. The superscript in α_p^1 denotes the pooled premium before the introduction of EDR technology. The insurance firms offer the pooling price of α_p^1 without knowing any individual's actual risk. There is no loss in privacy.

When EDR technology is introduced, consumers have a choice between using the technology and not using the technology; they can purchase insurance which requires monitoring by an EDR device or they can purchase insurance that does not require an EDR device. Consumers who do not use EDR will continue to pay a pooling price. Consumers who use EDR will pay an actuarially fair premium for their insurance since their driving risks – including how, where, and when they drive – are assumed to be perfectly revealed to the insurer.

When EDR is introduced, those consumers who adopt it face a loss in privacy but pay a premium based on their true risk p_i rather than one based on the average risk in the pool. Thus, those consumers for whom $u(W_1 - p_i) - u(W_1 - \alpha_p^1) > \beta_i \pi$ will adopt EDR, since their utility from insurance cost savings outweigh their loss in utility from their loss in privacy.

However, the consumers who adopt EDR are those with relatively low β_i and relatively low p_i since for them the gain from a reduction in premiums exceeds their loss in utility from a reduction in privacy.[10] For this reason, the pooling price must increase following the introduction of EDR technology. The average pooled risk for the remaining group increases to p_p^2 where $p_p^2 > p_p^1$.

The new average pooled risk can be written as a function of the average pooled price from before the introduction of EDR technology, $p_p^2\left(\alpha_p^1\right) \equiv \dfrac{\int_0^{\infty} \int_{\alpha_1{}^P - \beta_i \pi}^{1} p_i f\left(p_i, \beta_i\right) dp_i d\beta_i}{\int_0^{\infty} \int_{\alpha_1{}^P - \beta_i \pi}^{1} f\left(p_i, \beta_i\right) dp_i d\beta_i}$. For clarity, $\dfrac{\partial p_p^2\left(\alpha_p^1\right)}{\partial \alpha_p^1} > 0$ since the higher the original risk, the higher the resulting pooled price after EDR has been introduced.

Given the increased average risk-level in the pool, competitive insurers would require a higher premium. The new, higher pooled premium will lead to further defections from the pool. As the iterative process continues, the pooling price increases and alters the opportunity set for the consumers who are pooled.

An equilibrium is a set of contracts $(\alpha_p^*, \mathbf{p_i})$ (where α_p^* is the equilibrium pooling price for all consumers remaining in the pool and $\mathbf{p_i}$ is the vector of individual's actuarially-fair EDR

[10] Consider that for any two consumers with identical privacy valuations, the consumer with a lower probability of an accident will be more willing to use EDR. Also consider that for any two consumers with identical probabilities of accidents, the consumer with a lower privacy valuation will be more willing to use EDR.

contracts) such that no insurer can profitably deviate by offering any other contract or contract set and all consumers choose their most preferred contract from among those offered.

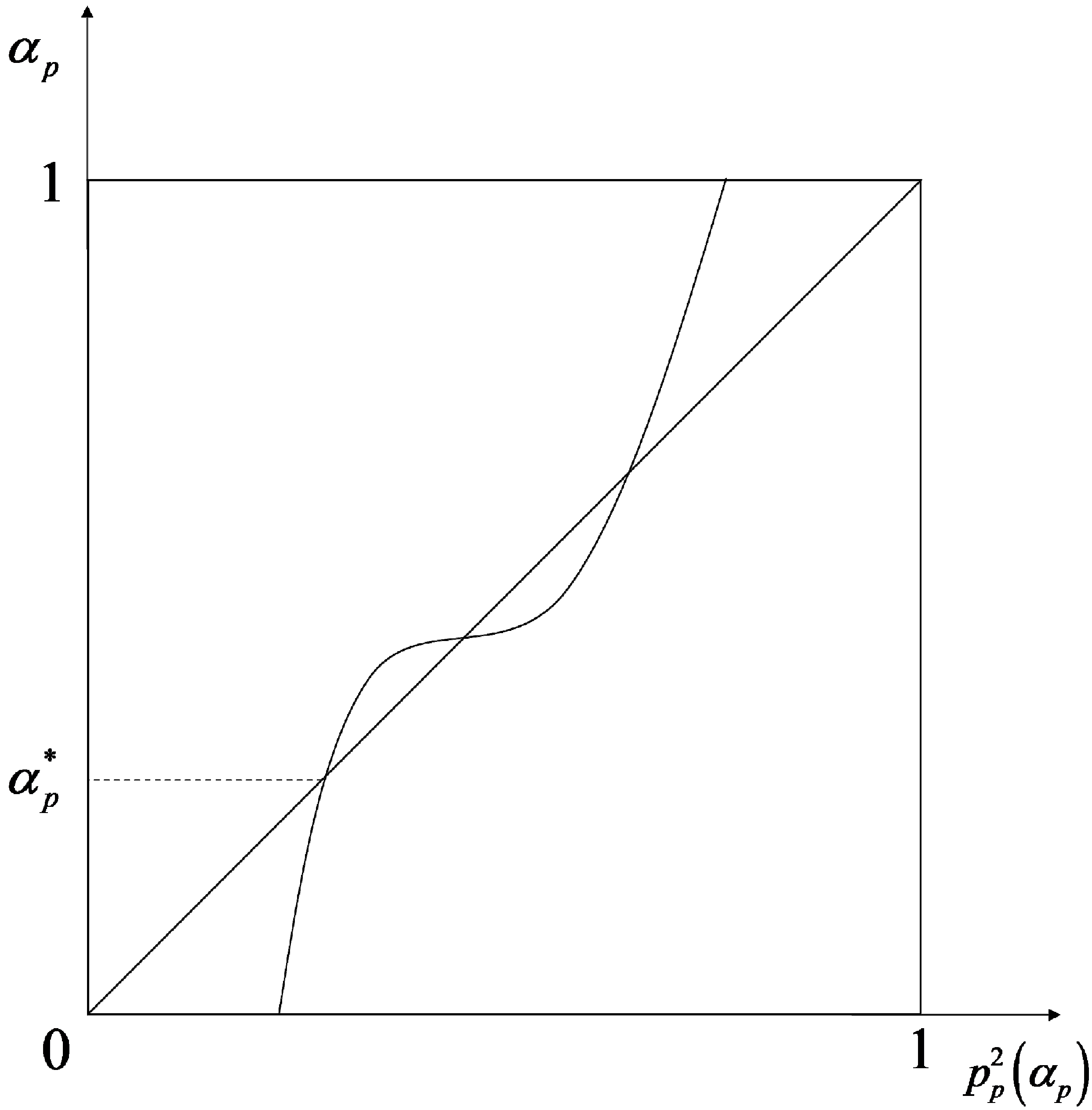
Given $(\alpha_p^*, \mathrm{p_I})$, all consumers for whom $u\left(W_1 - p_i\right) - u\left(W_1 - \alpha_p{}^*\right) > \beta_i \pi$ have adopted the EDR technology. Furthermore, all consumers remaining in the pool do not wish to deviate from the pooled price since it is not in their utility maximizing interest to do so since they receive more utility from their privacy than they do from the cost savings that EDR provides.

In equilibrium, EDR contracts must be priced such that the premium is equal to the probability of an accident for that individual. A pooling contract must be priced to be equal to the average risk of all those consumers in the pool.

It is straightforward to show the existence of the pooling equilibrium if the distribution function $F\left(p_i, \beta_i\right)$ is continuous: a competitive equilibrium requires that the pooling price be equal to the average risk of those in the pool, which is between 0 and 1. The average risk of those in the pool is an increasing function of the pooling price. As the pooling price increases, more consumers deviate to the EDR contract. Figure 1 illustrates the existence of such an equilibrium. The curved line represents the average risk $p_p^2\left(\alpha_p\right)$ of those in the pool for any given pooling price α_p. A competitive equilibrium must be on the diagonal so that the pooling price earns zero profits. If the diagonal is only crossed once, that would be the equilibrium. With multiple crossings, as in Figure 1, the lowest crossing point (which occurs at α_p^*) is the equilibrium. Evidently, a lower price than α_p^* would result in losses to any firm which offered it, while a higher price would attract no customers.

To show the existence of this equilibrium it is intuitive to consider the pooling price at the extremes: when the pooling price is equal to zero and when the pooling price is equal to one. If the pooling price was zero, every driver would enter the pool because it would be in their interest to receive free insurance. The average risk in the pool would then necessarily be above the offered price of zero, as in Figure 1. If the pooling price was 1 (the highest price possible), the average risk in the pool would necessarily be below the pooling price of 1 since some consumers with an expected loss below the highest possible cost would deviate and use EDR technology instead. The combination of these two scenarios gives us the existence of at least one crossing point as shown in Figure 1.

Figure 1



There is a one-to-one relationship between the average pooled risk and the average pooled price, as shown by the curve. Profit equals zero anywhere on the diagonal line. The lowest crossing represents the equilibrium pooling price. At any price above this, a firm would not sell any policies; at any price below this, a firm would earn negative profits.

Welfare

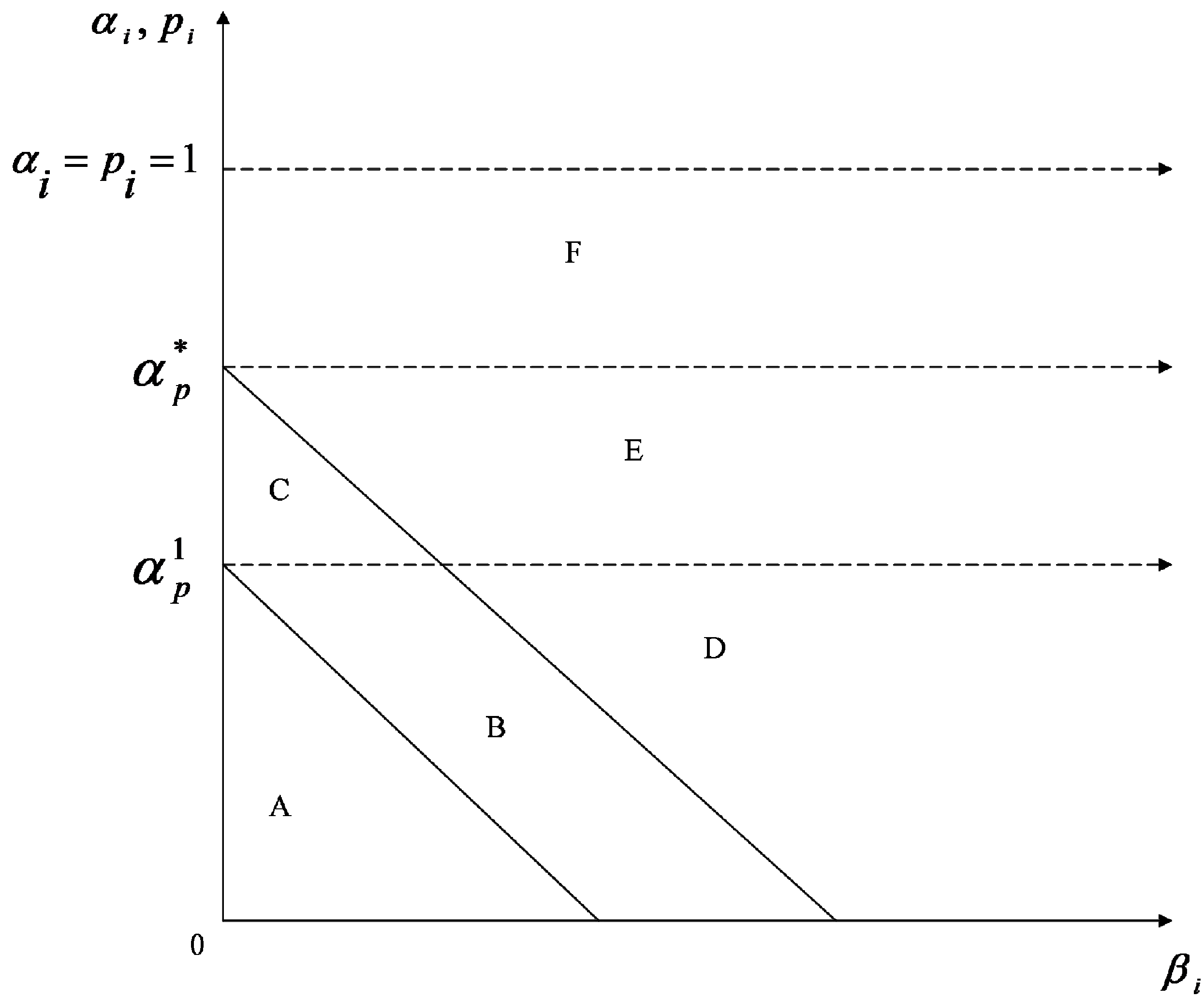
The aggregate overall change in utility due to the implementation of EDR is equal to equation (1.3).

$$\Delta U = \int_0^{\infty} \int_0^{\alpha_p^* - \beta_i \pi} \left(u\left(W_1 - p_i\right) - u\left(W_1 - \alpha_p^1\right) - \beta_i \pi \right) dp_i d\beta_i + \int_0^{\infty} \int_{\alpha_p^* - \beta_i \pi}^{\infty} \left(u\left(W_1 - \alpha_p^*\right) - u\left(W_1 - \alpha_p^1\right) \right) dp_i d\beta_i \quad (1.3)$$

The first integral represents the (possibly negative) gains to consumers who switch to EDR technology. They pay a different premium than originally, and give up their privacy. The second integral represents the losses to consumers who remain in the pool, and pay a higher premium following the implementation of EDR for some consumers.

Figure 2 illustrates the effects of introducing EDR. Without EDR, there is a pooling price α_p^1. Those consumers with risks $p_i < \alpha_p^1$ are subsidizing those with $p_i > \alpha_p^1$ and all consumers have no loss in privacy. When EDR is introduced, the consumers in area A adopt it initially, which forces the pooling price to increase to reflect the new, higher average risk in the pool. The new, higher pooling price encourages even more consumers to leave the pool, ultimately resulting in an equilibrium pooling price of α_p^*. At that point, all those consumers in areas A, B and C have adopted EDR, and the others remain pooled because it is in their interest not to give up their privacy since their cost savings will not outweigh their privacy losses.

Figure 2



Only the consumers in area A are better off than before the introduction of EDR technology. These consumers give up privacy (which they do not highly value) in exchange for a reduction in their insurance premium. Consumers in areas B and C accept the technology because the increased pooling price changes their opportunity set and makes it beneficial for them to give up their privacy. Consumers in area B pay less than initially, but the reduction in premium is insufficient to compensate them for their loss in privacy. Consumers in area B are thus net losers relative to the original non-EDR world. Consumers in area C are worse off in every way, as they forgo privacy *and* pay a higher premium than before the introduction of EDR technology. Consumers in areas D, E and F do not adopt EDR and so maintain their privacy, but they pay a higher insurance premium.

It is privately efficient for consumers in area A to give up their privacy, exactly in the way that Stigler (1980) suggests; subsequently, it is efficient for consumers in areas B and C to give up their privacy too. However, from a social welfare perspective, as equation (1.3) highlights in this model, EDR is likely to be harmful. The total premiums paid will be the same with and without EDR, although clearly their distribution changes, as consumers in areas A and B pay less, while consumers in areas C, D, E and F pay more. The reduction in aggregate welfare arises because consumers in areas A, B and C suffer a reduction in privacy, while aggregate premiums paid remain unchanged.

Separation through screening

Now suppose that partial insurance is possible, enabling a separating equilibrium in the spirit of Rothschild and Stiglitz (1976) and Wilson (1977). Suppose that there are only two risk types who are continuously distributed according to their preference for privacy. In this case, there is no cross-subsidization between risk types, and each consumer receives insurance based on fair odds. However, low-risk types will only have incomplete insurance, while high-risk types will obtain full insurance.

With EDR, low-risk types have the opportunity to obtain full insurance at actuarially fair prices but at the cost of reduced privacy. Those consumers with a relatively low valuation of privacy will adopt EDR technology, and they will be better off. Note that because there is no cross-subsidization, (high risk types have full insurance and low risk types have partial insurance at actuarially fair prices) this has no effect on any other consumers. This implies an aggregate welfare increase from the implementation of EDR since no consumer will accept it unless his total increase in welfare from lower prices and greater insurance coverage outweighs his loss of privacy.

Conclusion

With EDR, low-risk types have the opportunity to obtain full insurance at actuarially fair prices, but at the cost of reduced privacy. The consumers for whom privacy valuations are relatively low will adopt EDR technology if they are subsidizing other members of the pool—they will be better off because of the cost savings they realize. The removal of their subsidy to the pool requires the remaining members of the pool to bear higher costs which alter the opportunity sets of those still remaining in the pool.

The difference between the full insurance and screening case illuminates the welfare effects of EDR. The price of insurance, in a competitive market, must reflect its average cost. If EDR does not reduce the average cost of insurance (which it cannot if it has no effect on the actual probability of accidents), its effects must be on privacy and on the amount of insurance purchased. If EDR does affect moral hazard, the overall welfare results are ambiguous without knowing the magnitudes of the two effects.

In the model with mandatory full insurance and pooling, the reduction in privacy constitutes the entire aggregate welfare impact. In the screening case, there is a trade-off that occurs between loss of privacy and increased insurance coverage for risk-averse consumers, which is dominated by the gains from increased insurance coverage.

In this brief note, we have considered the market implementation of event-data-recorders (EDRs), telematics and related monitoring technologies which allow insurers to obtain very extensive information about how, when, and where consumers drive. This should, in turn, permit more precise insurance pricing, which may allow low-risk drivers to reduce their insurance costs, but at a cost of a loss in privacy. We have considered the case of full insurance with pooling, and the case of screening contracts, and shown that the welfare effect depends on which case holds. We have not directly considered the moral hazard implications of EDR technology, which may be very important and could outweigh the losses in privacy.

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