INCENTIVE MECHANISMS FOR SAFE DRIVING: A COMPARATIVE ANALYSIS WITH DYNAMIC DATA

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Abstract—Road safety policies often use incentive mechanisms based on traffic violations to promote safe driving—for example, fines, experience rating, and point-record driver’s licenses. We analyze the effectiveness of these mechanisms in promoting safe driving. We derive their theoretical properties with respect to contract time and accumulated demerit points. These properties are tested empirically with data from the Quebec public insurance plan. We find evidence of moral hazard, which means that drivers who accumulate demerit points become more careful because they are at risk of losing their license. An insurance rating scheme introduced in 1992 reduced the frequency of traffic violations by 15%. We use this result to derive monetary equivalents for traffic violations and license suspensions.

1. Introduction

Since the 1970s fatality rates due to road traffic accidents have decreased steadily in developed countries, although risk exposure increased concomitantly (OECD, 2005). For example, over the past ten years, the road fatality rate decreased by 40% in France. However, the implied social cost of road accidents remains high (Doyle, 2005). A major reason for the improvement of the situation in the OECD has been the development of incentives for safe driving. Experience rating schemes used by the insurance industry have incentive properties (see Boyer & Dionne, 1989; Abbring, Chiappori, & Pinquet, 2003). They are supplemented by point-record driver’s licenses based on traffic violations. In many countries, each convicted traffic offense is filed with a specific number of demerit points. When the accumulated number of points exceeds a given threshold, the driver’s license is suspended. Point removal clauses are added so that this penalty can be avoided in the long run. A point-record driver’s license implemented in Quebec in 1978, together with a no-fault insurance plan for bodily injuries, replaced a tort system. The road fatality rate decreased by 50% during the fifteen years that followed.3

In Quebec, the Société de l’Assurance Automobile du Québec (SAAQ) is a public monopoly that provides coverage for bodily injury. The SAAQ is also in charge of accident prevention and control, including the management of driver’s licenses. Before 1992, the rating structure for bodily injury insurance was completely flat. Since December 1, 1992, the public authorities in Quebec have implemented an experience rating system based on accumulated demerit points. This mechanism was added to other incentives, such as fines, the point-record driver’s license in force since 1978, and the private sector insurance rating for coverages other than bodily injury.

This paper analyzes the incentive properties of fines, point-record driver’s licenses, and experience rating based on traffic violations. Studies on incentive mechanisms for road safety have appeared in the economic literature for many years (Peltzman, 1975; Landes, 1982; Boyer & Dionne, 1987). In the presence of asymmetric information, insurers use partial insurance or experience rating to improve resource allocation. Both systems have proved to be efficient for handling moral hazard and adverse selection. Empirical tests have measured the effectiveness of such mechanisms for road safety (Sloan, Reilly, & Schenzler, 1995; Boyer & Dionne, 1989) and the presence of residual asymmetric information problems in insurers’ portfolios (Chiappori & Salanié, 2000; Dionne, Gouriéroux, & Vanasse, 2001). More recently, Abbring et al. (2003) designed a new test based on the dynamics of insurance contracts to detect the presence of moral hazard. Their model makes it possible to separate the moral hazard effect on accidents from unobserved heterogeneity. They found no evidence of moral hazard in the French car insurance market. The convex structure of the French bonus-malus system is used to show that the optimal effort level exerted by a rational policyholder increases after a claim at fault. In our study, insurance pricing is not the major incentive scheme but rather a measure used to complement fines and the point-record driver’s license. Moreover, the pricing scheme of the Quebec public automobile insurance is an increasing step function of past demerit points.

Insurance pricing may not suffice as a tool for designing an optimal road safety policy because it may not create the appropriate incentives for reckless drivers (Sloan et al., 1995). Bourgeon and Picard (2007) show how point-record driver’s licenses provide incentives for road safety among

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1 These clauses and their incentive properties are detailed in section III.

2 North America preceded Europe in the design of such systems. Point-record driver’s licenses were introduced in 1947 in the United States, Germany, France, and Spain implemented these mechanisms in 1974, 1992, and 2005, respectively.

3 We do not have information on factors different from the incentive schemes analyzed in this paper that might have explained this decrease. This study is performed in a no-fault environment. For a recent comparison of strict liability and a negligence rule for risk incentives trade-off, see Fagart and Fluet (2009).
normal drivers (those who respond to the usual incentive schemes) when the judicial system or the insurance market fails to provide optimal incentives. Point-record driver’s licenses also allow the government to incapacitate reckless drivers because fines for traffic violations are bounded above in many jurisdictions. Bounded fines exist for different reasons: many offenders are judgment proof and are unable to pay optimal fines; many drivers are expected to escape from paying tickets issued by the authorities when fines are very high; and society thinks it is unfair that rich and reckless drivers will pay high fines and continue to drive dangerously (Shavell, 1987a, 1987b). However, fines do reinforce the effectiveness of the point-record mechanism by providing normal drivers with more incentives. In Bourgeon and Picard’s model, which uses only two levels of prevention, the optimal fine must be set at the maximal level and must be neither progressive nor regressive. These authors also discuss the optimality of point-removal mechanisms as a screening device. Public intervention can be justified when there is a significant difference between the private and the social cost of human lives (Viscusi, 1993). Finally, drivers may be unaware of their own accident or infraction probabilities or may misunderstand some features of the incentive environment.

We present the database in section II, as well as our first empirical results related to the introduction of the new pricing policy implemented in 1992. The point-record mechanisms (driver’s license suspensions and insurance pricing) are described in section III, and their incentive properties are investigated in an optimal behavior model in which time and effort are continuous. If incentives are caused by fines and by the point-record driver’s license, we show that the optimal effort level increases globally with the number of demerit points accumulated and decreases with the seniority of nonre-deemed traffic violations, if any. Traffic violation risk varies conversely, as it decreases with the effort level.

These results are compared with the data in section IV. The observed dynamics on the drivers result from the incentive effects and the revelation with time of hidden features in risk distributions (that is, an unobserved heterogeneity effect). Let us compare these two effects at the time and event (accident or traffic violation) level of the data dynamics. Drivers with more traffic violations committed during a given period are riskier with respect to hidden features in risk distributions. Hence, unobserved heterogeneity entails a risk reassessment after each event, and the event effect of risk revelation counters the corresponding incentive effect of the point-record driver’s license. The revelation effect on the risk level of a period without traffic violations is negative. The time effect of unobserved heterogeneity is also converse to that of the incentive effect, which raises an identification issue in the interpretation of the observed dynamics on the drivers.

Abbring et al.’s (2003) test for moral hazard can be used if there are no time effects in the incentives. Because the time effects are important in Quebec’s point-record system, we use another approach. We test for an increasing link between traffic violation risk and the number of demerit points. Rejecting this assumption amounts to finding evidence of moral hazard (ab absurdo, because of the increasing event effect created by unobserved heterogeneity). In section IVB, the incentives created by the threat of driver’s license suspension are found to increase with accumulated demerit points. These findings confirm the theoretical analysis.

The insurance rating scheme introduced in 1992 reduced the frequency of traffic violations by 15%. In section IVB, we link the incentive levels of the three point-record mechanisms as derived from the theoretical analysis of section III and the observed efficiency of these mechanisms. Monetary equivalents for traffic violations and license suspensions are derived from this analysis. Conclusions are drawn in section V and technicalities are relegated to an appendix available online at http://hal.archives-ouvertes.fr/hal-00414479/fr/.

II. Presentation of the Database and Preliminary Empirical Results

Our database represents roughly 1% of the SAAQ portfolio. The panel covers the period from January 1, 1983, to December 31, 1996. A first sample of 40,000 license holders was selected at random at the beginning of 1983, and about 300 young drivers were added each following year. The attrition rate per year is close to 1.5%, which is very low compared with the private sector. Due to the monopolistic status of the SAAQ, leaving the company means that drivers lose their license, which explains the low attrition rate. The endogenous attrition is not very high. It was estimated from a bivariate probit model on traffic offenses and departures from the sample. A score test for the nullity of the correlation coefficient between the two equations was performed with the regression components set used in section IV. The null hypothesis was not rejected at a 5% significance level. Hence, the attrition risk adds no significant information to the assessment of traffic violation risk.

The personal characteristics of each driver are available on the driver’s license for the current period. These characteristics are used as regression components in the empirical study. Several types of events are recorded in the database:

- Accidents that have led to a police report. Only those with bodily injury are compensated by the SAAQ.

4 Increases in premium after an event and “no claims discount” clauses observed in non-life insurance can be explained by the revelation effect of unobserved heterogeneity.

5 Selecting at random 1% of the new license holders every year would evidently have been a preferable sampling procedure. One thousand new license holders would then have been selected every year, as the entry rate in the SAAQ portfolio is close to 2.5%.

6 Binary variables related to traffic offenses and attrition were created on a monthly basis and explained with the covariates used in section IVA. The score test statistic is equal to 0.34. Hence, we do not reject the nullity of the correlation coefficient at the usual significance levels.
Convicted violations of the Highway Safety Code, together with the number of demerit points used in the point-record mechanisms. The number of demerit points is based on the severity of the traffic violation. Their distribution is given in section IIID.

- Driver’s license suspensions, which are spells rather than events.
- Premium payments, which since the 1992 reform are related to accumulated demerit points. These payments are made every two years on the policyholder’s birthday.

Between 1985 and 1996, the average yearly frequencies of accidents with bodily injuries, accidents of all types (not including joint reports filed with private insurers), and traffic violations are 1.4%, 6.7%, and 16.9%, respectively. Figure 1 represents the relative frequencies derived from a one-year-centered moving average.7

There is an overall decline in the frequency of accidents, whereas the frequency of traffic violations remains more stationary. This may seem surprising, but it is explained by the evolution of the traffic control environment. For instance, the number of traffic control devices such as radars increased during the 1980s and 1990s. An increase in the rate of traffic offenses recorded by devices or police officers among those committed explains this relationship. Figure 1 shows evidence of several periods where the frequency of traffic violations increased along with opposite variations in the frequencies of accidents. A step-up in traffic control during these periods may well explain such observations.

A traffic violation committed by a driver must be selected twice in order to be filed with demerit points. It must first be recorded by a control device or a police officer. We already mentioned that the related selection rate had previously increased. Second, the offender must be convicted of the recorded traffic violation. The filing of a traffic violation is somewhat discretionary. Since the 1992 reform, for instance, drivers are being forced to pay more in premiums given demerit points, and we might expect police to be more hesitant to hand them out and to give warnings instead.8 The conviction rate is less likely to vary with time than the recording rate.

In figure 1, a downturn is also observed in the frequency of traffic violations just before the date of the reform that introduced the experience rating structure based on demerit points (December 1, 1992). The reform was announced on August 1, 1992, which may explain why the downturn starts slightly before December 1, 1992. The experience-rated premium was first applied at the contract anniversary following December 1, 1992, and used the complete two-year history of demerit points. Hence the new incentives for safe driving took effect for most of the drivers on August 1, 1992 (drivers with their next birthday after December 1, 1992).9 On average, the annual frequency of traffic violations was equal to 17.6%

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7 We begin in 1985 in order to match the regressions that follow because a two-year history is needed to obtain the accumulated demerit points. Data are first averaged over one year, to account for strong seasonal effects. A centered moving average derived on five fortnights is then performed twice in order to reduce the volatility of the series.

8 We thank a referee for suggesting this interpretation.

9 The SAAQ had the information on the drivers’ traffic violation history since 1978. Drivers with a contract anniversary falling between the announcement of the reform and its enforcement are not incited by the experience-rated premium before this anniversary. Incentives exist otherwise (for these drivers after their birthday and for all the other drivers since the announcement of the reform). A referee suggested using this natural experiment in order to disentangle the incentive effects of the reform from calendar effects. We did not obtain significant results. Four months is a short period, and on average only one driver out of twelve was not incited by the rating scheme during the period.
before the reform and 15.4% afterward, which corresponds to a 12.5% decrease. The 1992 reform can be interpreted as a laboratory experiment to test whether experience rating based on demerit points reduces traffic violations. Nonetheless, the lower rate of traffic violations following the 1992 Quebec reform may be due to the changes in other factors that influence driver behavior. Identifying the influence of these factors necessitates a control group that is not affected by the policy change. Unfortunately, we do not have access to such a control group because the insurer is a monopoly and bodily injury insurance is compulsory. In section IVB, we link the average decrease in the frequency of traffic violations before and after the 1992 reform to the overall effectiveness of incentive schemes.

Monetary and nonmonetary incentives for safe driving are based on traffic violations as well as the optimal behavior models presented in Section III. However, the actual social cost of road traffic is caused by accidents. To reconcile these two approaches, two results are worth mentioning. First, demerit points are good predictors of accidents. This is well documented in the literature and is confirmed in our data in section IVA. Second, the global stationarity of convicted traffic violation frequency observed in figure 1 concurs with a probable decrease in the frequency of committed traffic violations (see the already noted developments on selection rates). Lowering traffic violation risk through point-record mechanisms should also lower accident risk and the related social cost.

Finally, figure 1 shows that accidents with bodily injuries evolve in much the same way as those recorded in the SAAQ file. We include accidents of all types in the empirical analysis in order to obtain more stable results.11

III. Incentive Effects of Point-Record Mechanisms

A. Point-Record Mechanisms in Quebec

In this section, we describe Quebec’s point-record mechanisms, which are based on traffic violations, both monetary (insurance premiums) and nonmonetary (point-record driver’s license). Comparisons are made with respect to the mechanisms used in other countries.12 We investigate the incentive properties of point-record mechanisms in sections IIIB to IIID.

In many countries, driver’s license suspensions are based on demerit points. In Quebec, demerit points are assigned to convictions for traffic offenses, and their number depends on the traffic violation severity. When the accumulated number of demerit points reaches or exceeds a given threshold, the driver’s license is suspended. Before January 1990 this threshold was set at twelve in Quebec and has since been increased to fifteen.

In order to mitigate the social cost of license suspensions, point-removal systems exist for most point-record driver’s licenses. In Quebec, the demerit points related to a given driving offense are removed after two years. Hence, driver’s license suspensions depend on the demerit points recorded during the previous two years. Most of point-removal systems used in American states follow the same approach. The average number of demerit points per convicted offense is 2.4 in Quebec. It takes about six traffic violations within two years to trigger a license suspension, an unlikely outcome when the annual traffic violation frequency is 16.9%. However, the heterogeneity of risks is high, and a point-record driver’s license is also an incapacitating device for risky and reckless drivers through license suspensions. Another point-removal system consists of cancelling all the demerit points after a given period of violation-free driving. This mechanism was recently implemented in Spain, with a two-year seniority. The French driver’s license uses the two removal systems.

The experience rating structure introduced by the SAAQ on December 1, 1992, links each premium paid every two years to the demerit points accumulated over the previous two years. The rating structure is given in section IIID. Once the premium is paid, the driver is reinstated with an unblemished record. Thus the length of the record relevant to the derivation of optimal behavior never exceeds two years.

B. Basic Model for a Point-Record Driver’s License without Point Removal

Bourgeon and Picard (2007) analyze the incentive effects of point-record driver’s licenses using a binary effort variable. We extend their approach with a continuous effort level. Hence, the effectiveness of effort may also be a continuous function of contract time, a desirable property for empirical validation. We show that under fairly general conditions, a rational policyholder’s safe driving effort will increase with the number of demerit points accumulated.

We assume that the driver’s license is revoked when the driver reaches a total of $N$ demerit points. For simplicity, each convicted traffic violation is linked to one supplementary demerit point in this section. A driver with a suspended driver’s license is reinstated after a period $D$ with an unblemished record like that of a beginner.13 The duration $D$ may be fixed or random in the model. In Quebec, a license suspension is of random length because drivers must pass a new exam after a given period before recovering their license.14 A rational driver maximizes his or her expected lifetime utility expressed in dollars and derived from:

\[ U = \int_{0}^{\infty} e^{-rt} [W + \beta \cdot E(d)] \, dt \]

where $W$ is the initial wealth, $r$ is the discount rate, and $E(d)$ is the expected utility of driving.

See Manning et al. (1987) for the use of a control group in the assessment of a cost-sharing modification in the health insurance market.

Important variables in the regressions such as the number of accumulated demerit points have low frequencies for the highest values. It is hard to make an accurate estimate if the frequency of events is low, as is the case for accidents with bodily injury.

We focus on license suspensions in the comparisons. However, financial penalties are also associated with demerit points in some U.S. states.
• An instantaneous driving utility, $u_0$.
• A time-dependent disutility of effort, denoted as $e(t)$.$^{15}$ This effort level is linked to an instantaneous traffic violation frequency risk, denoted as $\lambda(e(t))$. The hazard function $\lambda(e)$ corresponds to a probability $p(e)$ in static or discrete time incentive models and is assumed to be a positive, decreasing, and strictly convex function of the effort level.

In this section, we suppose that there is no point-removal mechanism. In that case, the lifetime expected utility (we assume an infinite horizon) depends on only the number $n$ of accumulated demerit points and is denoted as $u_n$. The Bellman equation on the expected utility leads to

$$u_n = \frac{d_n}{r} - \frac{c_s(u_n - u_{n+1})}{r}, \quad (0 \leq n < N),$$

where $r$ is a subjective discount rate and $c_s$ is defined as

$$c_s(\Delta u) \equiv \min_{e \geq 0} e + [\lambda(e) \times \Delta u].$$

Technical details can be found in appendix A1. From equation (2), incentives are effective if we have $\Delta u > -1/\lambda'(0)$. In this equation, $\Delta u$ is the lifetime utility loss between the current state and the one reached after an additional traffic offense. Once quantified, $\Delta u$ is the monetary equivalent of this traffic violation. Values of this type are derived in section IVB. The function $c_s$ minimizes the sum $e + [\lambda(e) \times \Delta u]$, which is the disutility flow of both effort (short-term component) and the expected lifetime utility loss (long-term component). All $u_n$ are lower than $u_{max} = d_n/r$, the private lifetime driving utility without the point-record driver’s license. Equation (1) means that $c_s(u_n - u_{n+1})/r$ is the minimal private utility cost of the point-record mechanism for a driver with $n$ demerit points. The cycle of lifetime utilities is closed with a link between $u_0$ and $u_N$, the lifetime expected utility just after the suspension of the driver’s license. For instance, if the private disutility of driver’s license suspension is only the loss of driving utility during a period $D$, we have that

$$u_N = \beta u_0, \quad \beta = \exp(-rD).$$

The utilities are then derived from the recurrence equations (1) and (3). Optimal effort depends on the variation of lifetime utility $\Delta u$ because it minimizes the function defined in equation (2). The variable $\Delta u$ (the argument of $c_s$ in equation (2)), which determines optimal effort, will be referred to later as the incentive level. In this setting, optimal effort depends on the number $n$ of accumulated demerit points but not on time, and we denote it as $e_n$. We show in appendix A1 that $e_n$ increases with $n$ for any given value of $N$. The related frequency of violations $\lambda_n = \lambda(e_n)$ thus decreases with $n$. The intuition behind this result is the following. A given reduction in traffic violation risk is more efficient as the threat of the license suspension gets closer. Hence, the efficiency of effort increases with the number of demerit points accumulated, and we obtain an increasing link between this number and the optimal effort level. A parallel can be drawn with the “three strikes and you’re out” rule enforced in California to deter crime. The deterrence effect increases from one to two strikes (Helland & Tabarrok, 2007).$^{16}$

Fines represent another monetary incentive scheme applied in Quebec throughout the period investigated in this study. Let us denote $\tilde{fa}$ as the average fine for a traffic violation conviction. Given that fines and premiums are low in comparison to average wealth, risk aversion is not significant. If fines are combined with the preceding point-record driver’s license, the incentive level is equal to $\tilde{fa} + u_n - u_{n+1}$. This means that the average fine is added to the utility loss in the variable, which determines optimal effort. Besides, the optimal effort still increases with $n$ for a given value of the average fine.

C. Point-Record Driver’s Licenses with Point Removal

In Quebec, each traffic violation is redeemed at the end of a two-year period. Integrating this feature in the optimal behavior model is difficult because all the seniorities of nonredeemed driving offenses must be included as state variables in the dynamic programming equations. Lifetime utility is expected to increase with time for a given number of demerit points accumulated. Optimal effort depends on the difference between the existing utility and a substitute utility (that reached after an additional traffic violation). With the point-removal system in force in Quebec, the substitute utility increases with time, as does the existing utility. Time should have more value for worse situations, which implies that the substitute utility should increase faster than the existing utility. Optimal effort should thus decrease with time. Appendix A2 provides proof that optimal effort is continuous at the time of a point removal. Optimal effort is then expected to increase with each traffic violation in order to compensate for the decreasing link between time and effort. To summarize, we expect the effort level to increase globally with the number of demerit points accumulated and to decrease with the seniority of nonredeemed traffic violations if any.

Figure 2 illustrates the changes in the optimal traffic violation risk during a period that includes two violations and their point removal. The continuous time effect of incentives

$^{15}$ Safe driving effort can also reduce the expected disutility of accidents. If $e \rightarrow \delta(e)$ is the implied decrease in the disutility flow, replacing $e$ by $e - \delta(e)$ in the model includes the influence of safe driving effort on accident disutility.

$^{16}$ We thank a referee for suggesting this connection. A “strike” is a conviction for a serious felony, the equivalent of a demerit point. Three strikes entail a prison sentence of 25 years to life, which in our context would be the license suspension. Comparing the time to rearrest for criminals with one or two strikes in California, Helland and Tabarrok (2007) conclude that those with two strikes are less risky than those convicted twice, with one strike only. They thus observe an increase in the deterrence effect at the second strike.
balances the downward jump in risk after each violation. The incentive effects at the time and event level are the opposite of those created by the revelation of unobserved heterogeneity. The incentive properties of the point-removal system in force in Quebec are similar to those of a mechanism without point removal concerning the number of demerit points accumulated. In section IV, we use the model of section III B as a proxy for the incentive environment in Quebec.

D. Incentive Effects of Premiums Indexed on Demerit Points in Quebec

Table 1 presents the rating structure enforced for each driver’s license on the first contract anniversary following December 1, 1992. The premium paid every two years after this date depends on the number of demerit points accumulated in the previous two years. It does not represent the total premium for bodily injury insurance but rather the additional premium related to demerit points. This average premium, equal to $54.60, complements a yearly driver’s license fee for insurance coverage equal to $107.

In this section, the incentive properties of this rating structure are analyzed separately from the point-record driver’s license. An important input is the distribution of demerit points for a given driving offense, which we left out in section III B. Denoting \( f_j \) as the proportion of traffic violations with \( j \) demerit points, we have the following values:

\[
f_1 = 4.71\%; \quad f_2 = 52.32\%; \quad f_3 = 38.34\%; \quad f_4 = 2.83\%; \quad f_5 = 1.80\%.
\]

Table 1 shows that the premium is a step function of the accumulated demerit points. Because of the local nonconvexity of the premium, the incentives may not always increase with the number of demerit points accumulated. Consider, for instance, a policyholder just before her contract anniversary. The incentive level will be stronger with two accumulated demerit points than with four. With four points, it is indeed less than likely that the next traffic offense will trigger an increase in premium. The corresponding probability is 2.83 + 1.80 = 4.63\%, if we assume that the distribution of the \( f_j \) is independent of the accumulated demerit points. The incentives for safe driving are stronger at a two-point level because the probability of climbing a step in the rating structure after a traffic violation is close to 1. The result is in contrast to that obtained by Abbring et al. (2003) for the French bonus-malus scheme and its exponential structure. Hence, step pricing schemes may have poor incentive properties. They are employed because they are simple.

Let us design optimal behavior models based on this rating structure. Once the premium is paid, the driver is reinstated with an unblemished record. Hence, the optimal control model can be designed with the next contract anniversary as the horizon. Let \( \pi_n \) be the premium paid for \( n \) demerit points accumulated during a period of \( T = 2 \) years between two contract anniversaries. As we disregard the point-record driver’s license and its possible deprivation, the driving utility is no longer a parameter. However, we retain fines in the incentives for safe driving. We denote \( \Delta v_n(T) \) as the expected disutility of premiums and fines paid until the next contract anniversary, where \( T \) is the seniority of the last anniversary and \( n \) is the number of demerit points accumulated since that date. We have the terminal conditions

\[
\Delta v_n(T) = \pi_n, \quad \forall n = 0, \ldots, N.
\]  

If incentives are related to fines and insurance premiums, the incentive level is the sum of the average fine \( \overline{fa} \) and the expected variation of \( v_n(t) \) after a traffic offense (see appendix A3). Hence, optimal effort is determined by \( \overline{fa} + \Delta v_n(T) \), with

\[
\Delta v_n(T) = \left( \sum_{j=0}^{N} f_j v_{\min(n+j,N)}(T) \right) - v_n(T).
\]

Derivations show that the average of \( \Delta v_n(T) \) with respect to \( n \) does not vary much with time. The terminal values of \( \Delta v_n \) are derived from equations (4) and (5) and table 1. For \( n = 0, 2, 4 \), we obtain

\[
\Delta v_0(T) = 2.32; \quad \Delta v_2(T) = 47.65; \quad \Delta v_4(T) = 3.43.
\]

The incentives with two points accumulated are much stronger than with four points, which confirms the analysis.
following equation (4). The overall average of $\Delta v_g(t)$ with respect to $t$ and $n$ is close to $12$, a 9% increase for a $130$ average fine. In section IVB, this increase will be compared with the variation in traffic violation frequency before and after the reform.

IV. Empirical Results on the Incentive Effects of Point-Record Mechanisms

A. Point-Record Driver’s License

In this section, we analyze the data before the 1992 reform that introduced the experience rating scheme based on demerit points. Thus, the point-record driver’s license interacts only with fines. Regressions are performed from January 1985 (we need a two-year history to derive the accumulated demerit points) to December 1992, the date of the reform enforcement. We try to confirm the theoretical findings of sections IIIB and IIIC (that the effort level increases globally with the number of demerit points accumulated and decreases with the seniority of nonredeemed traffic violations, if any), and to find evidence of moral hazard in the data.

We estimate the hazard functions of convicted traffic offenses and accidents with a proportional hazards model (Cox, 1972). We retained the following specification:

$$\lambda^*_i(t) = \exp((x_i(t)\beta_j) + g_j(adp_i(t))) \times h_j(c_i(t)). \tag{7}$$

In equation (7), $\lambda^*_i(t)$ is the hazard function of type $j$ ($j = 1$ : traffic violation or $j = 2$ : accident) for driver $i$ at calendar time $t$. Regression components are denoted by the line vector $x_i(t)$. We retained the gender, driver’s license class, place of residence, age of the driver, calendar effects related to years and months, and the number of past license suspensions.$^{17}$ The number of demerit points accumulated in the previous two years is denoted as $adp_i(t)$. Let us comment on the expected shape of $g_1$, which links traffic violation risk to accumulated demerit points. The revelation effect of unobserved heterogeneity is increasing in $adp$ and is converse to the incentive effect. In the absence of moral hazard, $g_1$ should then be increasing. We will test the null hypothesis that $g_1$ is weakly increasing against the alternative that it is not ($g_1$ strictly decreases for at least some values), rejecting the null amounts to finding evidence of moral hazard.$^{18}$

Contract time $c_i(t)$ is integrated into the baseline hazard function $h_j$. The function $c_j$ is set at 0 at the beginning of the period. Then it is reset to 0 at each event that triggers a variation of the accumulated demerit points (traffic violation or point removal). This event-driven operation should eliminate interactions between calendar and contract-time effects.

Table 2 shows that $\hat{g}_1$ is increasing until $adp$ reaches the seven-point threshold, at which point the increasing property is no longer fulfilled, and $\hat{g}_1$ reaches a maximum at seven points. It is worth mentioning that the SAAQ warns the policyholders when their accumulated demerit points increase beyond a seven-point threshold.$^{19}$ When the accumulated demerit points are less than or equal to seven, the unobserved heterogeneity effects outweigh the incentive effects because $\hat{g}_1$ is increasing. Controlling for other covariates, a driver with seven accumulated demerit points is $\exp(0.974) = 2.65$ times riskier than a driver with a violation-free record. Hence, unobserved heterogeneity effects strongly outweigh incentives to drive carefully between zero and seven points. This result is reversed beyond seven points. For instance, a driver with seven accumulated demerit points who gets a supplementary two-point offense has a traffic violation risk that is 19% lower. As the unobserved heterogeneity effect is increasing with $adp$, the estimated risk reduction due to the incentive effect is greater than 19%. The $p$-values refer to tests for the null assumption: $g_1(7) \leq g_1(adp)$ (with $adp > 7$) versus the alternative, with one-sided rejection regions. For instance, the null assumption related to $adp = 8$ is rejected at the level α if $g_1$ is greater than $19\%$, and accepted otherwise. The results suggest that $g_1$ is not increasing beyond $adp = 7$, which shows evidence of moral hazard. A global test for the increasing shape of $g_1$ is presented in figure 3. Additional regression variables are gender, driver’s license class (nine levels), place of residence (sixteen levels), age of the driver (five slopes), number of past suspension spells (three levels), as well as calendar effects related to years (eight levels), and months (twelve levels). Number of observations: 3,492,868 duration-event indicator pairs, derived from 41,290 driver’s licenses. The durations are bounded above by one month.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Level</th>
<th>Frequency (%)</th>
<th>Traffic Violation Risk</th>
<th>$P$-value (HO: $g_1(7) \leq g_1(adp)$, $adp &gt; 7$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$adp$: 0 point$^a$</td>
<td>76.60</td>
<td>0</td>
<td>0</td>
<td>0.243</td>
</tr>
<tr>
<td>Number of accumulated demerit points 1 point</td>
<td>0.39</td>
<td>0.311</td>
<td>0.496</td>
<td></td>
</tr>
<tr>
<td>2 points</td>
<td>9.36</td>
<td>0.500</td>
<td>0.504</td>
<td></td>
</tr>
<tr>
<td>3 points</td>
<td>6.23</td>
<td>0.522</td>
<td>0.449</td>
<td></td>
</tr>
<tr>
<td>(last two years)</td>
<td>4 points</td>
<td>1.92</td>
<td>0.794</td>
<td>0.496</td>
</tr>
<tr>
<td>5 points</td>
<td>2.09</td>
<td>0.854</td>
<td>0.595</td>
<td></td>
</tr>
<tr>
<td>6 points</td>
<td>1.25</td>
<td>0.873</td>
<td>0.647</td>
<td></td>
</tr>
<tr>
<td>7 points</td>
<td>0.72</td>
<td>0.974</td>
<td>0.601</td>
<td></td>
</tr>
<tr>
<td>8 points</td>
<td>0.55</td>
<td>0.876</td>
<td>0.0130</td>
<td>0.736</td>
</tr>
<tr>
<td>9 points</td>
<td>0.43</td>
<td>0.764</td>
<td>0.0001</td>
<td>0.797</td>
</tr>
<tr>
<td>10 points</td>
<td>0.32</td>
<td>0.786</td>
<td>0.0002</td>
<td>0.842</td>
</tr>
<tr>
<td>11 points</td>
<td>0.06</td>
<td>0.906</td>
<td>0.2328</td>
<td>0.522</td>
</tr>
<tr>
<td>12 points</td>
<td>0.04</td>
<td>0.378</td>
<td>0.0001</td>
<td>0.810</td>
</tr>
<tr>
<td>13–14 points</td>
<td>0.04</td>
<td>0.571</td>
<td>0.0004</td>
<td>0.222</td>
</tr>
</tbody>
</table>

$^a$The reference level.

$^{17}$ Comprehensive regressions based on two-year periods can be found in Dionne et al. (2001).

$^{18}$ We thank a referee for suggesting this formulation of the test.

$^{19}$ Drivers are not informed when offenses are redeemed.
This figure presents a graphical test where the null is the weakly increasing shape of $g_1$ as a function of $adp$, the number of accumulated demerit points. The test statistic is a squared distance between the unconstrained estimation of $g_1$ (thick line) given in table 2, and the set of weakly increasing functions of $adp$. The metric is that of the Wald asymptotic test, and the weakly increasing function closest to $g_1$ is represented by the dashed line. The statistic is equal to 43.18, and its asymptotic distribution is less than that of a $\chi^2(13)$ in the sense of first-order stochastic dominance. This leads us to reject the increasing shape assumption for every significance level greater than $42 \times 10^{-6}$. As an absence of incentive effects entails an increasing shape for $g_1$ (unobserved heterogeneity effect), rejecting the null shows evidence of moral hazard.

Table 2 shows less evidence of moral hazard on accident risk than on traffic violation risk, as the estimation of $g_2$ increases until $adp = 10$. A possible interpretation is that we cannot separate at-fault from no-fault accidents. In the literature, the incentive effect is usually higher with at-fault accidents. Besides, drivers nearing the license suspension threshold might also apply opportunistic strategies regarding traffic violations (for example, paying more attention to radar) without otherwise modifying their attitude toward road traffic risk.

The estimated hazard function from the traffic violation equation globally decreases with time. This means that the continuous time effect created by the revelation of unobserved heterogeneity outweighs the incentive effects (see figure 2 and the discussion that follows). This is not surprising, given that the average increase of $g_1$ in table 2 (a vast majority of drivers have fewer than seven demerit points) must be balanced by a negative time effect in order to obtain stationary risk levels on average. As effort is expected to decrease with time only if the number of demerit points accumulated is greater than zero, the statistical analysis can be refined with a stratified proportional hazards model. Two strata can be created, depending on whether the variable $adp_i(t)$ is equal to 0 or not. On both strata, we observe a decreasing shape for the estimated hazard function.

B. Incentive Effects of the 1992 Reform and Monetary Equivalents for Traffic Violations and License Suspensions

In this section, we assess the efficiency of the 1992 reform. We compare its incentive level to those of fines and of the point-record driver’s license. We relate the efficiency of the reform to its relative weight in the three incentive mechanisms, and we infer results on the shape of the link between the cost and efficiency of effort. Finally, we derive monetary equivalents for traffic violations and license suspensions from the estimated efficiency of incentives created by a supplementary traffic violation.

In section II, we mentioned a 12.5% decrease in the average frequency of traffic violations before and after the reform, which introduced the experience rating structure based on demerit points. This result changes slightly if we control with the regression components used in table 2. A regression estimated from 1985 to 1996 with the covariates of section IVA and a dummy related to the period following December 1, 1992, associates the reform with a 15% decrease. The results of section IID (for instance, equation (6)) suggest that the number of demerit points accumulated since the previous anniversary should influence the effectiveness of the 1992 reform. However, we did not obtain significant results in this direction. The drivers’ limited knowledge of the environment could explain this poor result, a point developed later.

20 Results are available from the authors on request.

21 Stratification in a proportional hazards model means that Cox likelihoods (of a multinomial logit type) are derived for each stratum and then multiplied together. In other words, an individual with an observed event is assumed to have competed only with other individuals in the same stratum and at risk at the same date. However, the same coefficients for the covariates are used across all strata.

22 We retained the covariates used in table 2 except for dummies related calendar effects and to the number of past license suspension spells. The estimated parameter for the reform dummy is equal to $-0.163$, and the related standard deviation is equal to 0.008. Hence, the reform effect is conclusive at the usual tests significance levels.
We perform an overall comparison of the three incentive schemes. We use the model without point removal of section IIIB to analyze the incentives for drivers in Quebec. Before the 1992 reform, fines were supplemented by a point-record driver’s license. Optimal effort after \( n \) nonredeemed traffic violations depends on the incentive level—that is, the argument of the function \( c_{\lambda} \) defined in equation (2). This level is equal to \( fa + u_n - u_{n+1} \) (see section IIIB). The average fine \( fa \) is equal to $130, and the 1992 reform entails an average increase in the incentive level equal to $12 from section IIID. At this point, it seems interesting to relate optimal frequency risk and the incentive level. This relation can be assessed from the elasticity between the former and the latter variable. When the incentives are effective, it can be shown that this elasticity is less than \(-1\) if and only if \( \log(\lambda) \) is a concave function of effort (elasticity and concavity are considered locally; see appendix A5 for a proof). A global elasticity equal to \(-1\) is linked to an exponential decay of \( \lambda \). With \( \lambda(e) = \lambda(0) \times \exp(-e) \), the optimal risk level as a function of \( fa + \Delta u \) (the incentive level) is equal to \( 1/(\alpha \times (fa + \Delta u)) \) if the incentives are effective.

We now apply this result to the 1992 reform. As the reform entailed a significant reduction in traffic risk regardless of the number of demerit points accumulated, we can assume that incentives are effective for a representative driver.\(^{23}\) This leads us to analyze the elasticity between traffic violation risk and the incentive level. Suppose that we leave out the modifications of incentive levels due to the aggregation of incentive mechanisms. Then we can relate:

- On the one hand, a 15% reduction in the frequency of traffic violations since the 1992 reform.
- On the other hand, a relative increase in the incentive level ranging between 9% and 10%. Indeed, the 1992 reform entails a $12 average increase in the incentive level. This increase supplements the other components of the incentives—the $130 average fine and the utility variation for the point-record driver’s license. In table 2, the point-record driver’s license offers significant incentives beyond a seven-point threshold, a result corresponding to only a minority of drivers (1.4%). The contribution of the point-record driver’s license to the incentives is low compared with that of fines.

This suggests that the elasticity between the optimal frequency risk and the incentive level is less than \(-1\) in this case. This result is linked to a locally concave shape of \( \log(\lambda) \) for the representative driver. However, external effects could also explain the reduction in the frequency of traffic violations. We cannot eliminate these effects because there is no control group that is not affected by the reform. Besides, the elasticity would be modified if the distribution of demerit points for a given driving offense (see equation (4)) was wrongly perceived by the drivers. The $12 contribution of the reform to the incentive level is low because of the high frequency of drivers without demerit points since the previous birthday (87%) and the low incentive level of the reform for these drivers (see equation (6)). This level depends largely on the probability of moving up a step in the premium schedule after an additional traffic violation, which must be associated with four demerit points or more. If the perceived frequency of corresponding traffic violations was greater than the actual one \((f_j + f_s = 2.83 + 1.80 = 4.63\%)\), the variation of the incentive level induced by the reform would increase. In that case, the elasticity would be closer to 0.

Finally, let us assess monetary equivalents for a traffic violation and a license suspension. The monetary equivalent of a traffic violation is the component of the incentive level related to the point-record driver’s license. It is equal to the loss of lifetime utility after a traffic violation, which depends on the number of traffic violations accumulated. A value can be derived from the effectiveness of effort estimated in table 2 and from the link between efficiency of effort and the incentive level. An additional traffic violation beyond seven accumulated demerit points entails a reduction of traffic violation frequency of close to 20%. Although these drivers cannot be seen as representative, we will apply the elasticity derived from the preceding developments. If the 9% increase in the incentive level induced by the 1992 reform entails a 15% reduction in the frequency of traffic violations, a 20% decrease in traffic violation frequency is associated with a 12% increase in the incentive level. The implied loss of lifetime utility depends on the traffic violation frequency risk \( \lambda \), but mostly on the discount rate \( r \) (see appendix A6). With \( \lambda = 0.15 \), the monetary equivalent of an additional traffic violation for these drivers belongs to the interval [\$120, \$195] if \( r = 3\% \), and to [\$411, \$557] if \( r = 6\% \). Besides, the growth rate of this monetary equivalent with respect to the number \( n \) of nonredeemed traffic violations falls between \( r/\lambda_n \) and \( r/\lambda_{n+1} \), which \( \lambda_n \) is the optimal traffic violation frequency related to \( n \). Monetary costs for license suspensions are then obtained by adding the costs of traffic violations until the crossing of the demerit point threshold. Starting from a zero-point record and assuming that six traffic violations are needed to trigger a license suspension, the monetary cost of a license suspension is bounded by $700 and $1,178 if \( r = 3\% \) and if \( \lambda_0 = 0.17; \lambda_1 = 0.17; \lambda_2 = 0.16; \lambda_3 = 0.15; \lambda_4 = 0.12; \lambda_5 = 0.09 \).\(^{24}\) A misperception of the environment could modify the monetary equivalents of traffic violations and license suspensions. In the discussion on the elasticity between the optimal frequency risk and the incentive level, we argued that an overestimation of the frequency of severe traffic violations would increase the perceived incentive effect of the 1992 reform. The $12 average effect of the reform on the incentive level should then be upgraded, and the monetary equivalents of traffic violations and license suspensions should also be upgraded.

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\(^{23}\) From section IIIB, a sufficient condition to have this result is that the average fine is higher than the threshold \(-1/\lambda(0)\) beyond which the incentives are effective.

\(^{24}\) These values correspond to an effort level that increases with the number of demerit points accumulated.
V. Conclusion

In this paper, we analyze the properties of policies designed to promote safe driving. Three important incentive mechanisms for road safety are used in Quebec. When the Quebec government introduced a no-fault insurance regime in 1978, it implemented a point-record driving license to maintain incentives for road safety. Because prevention activities are not observable by the public insurer, the new mechanism uses drivers’ accumulated demerit points to approximate past safety activities and increase incentives to reduce infractions. Under moral hazard, drivers who accumulate demerit points become more careful because they are at threat of losing their license. This result was confirmed from the data. Otherwise, we would have accepted an increasing link assumption between accumulated demerit points and traffic violation risk.

Fines are on average the most efficient device, but they are associated with a uniform incentive level. We designed our incentive models with a representative driver, but there is, of course, heterogeneity in the individual parameters, such as the threshold beyond which the incentives are effective. We did not have wealth variables at hand, and an interesting empirical issue would have been to cross such variables with a reform dummy in risk assessment.

The experience-rated premium based on accumulated demerit points is a monetary point-record mechanism. The empirical results exhibit a rather uniform effectiveness after its enforcement in 1992—a 15% decrease in the frequency of traffic violations. Its incentive effects do not strictly increase with the accumulated demerit points, however, because of the steps in the rating structure. The actual incentive effect of the reform looks more like that induced by an increase in the average fine. The SAAQ modified its rating policy in 2008, with a premium increase from the first demerit point.

Regulations are not self-enforcing. To successfully achieve a reform, the regulator must implement enforcement activities and bear the costs thereof. In our application to road safety, the police is the most important enforcer of the different incentive schemes. Police officers have a limited capacity to modify the penalties for a given infraction but may affect the detection probabilities based on the aggregate conviction cycles, the driver’s accumulated demerit points, or other tasks. When analyzing our results, we must consider the effect of these potential behaviors. For example, is it possible that when accumulated demerit points are greater in a given file, police officers have an incentive to issue them more or less often because of risk of the driver’s losing his license?

We did not have precise information to control for these factors. It is well documented that the police collaborate very well with the Quebec public insurer and government. There is, consequently, a low probability that aggregate safety scores would have affected police behavior without the agreement of the government, which is assumed to be fully committed to its road safety policies. Regarding the effect of accumulated demerit points, we do not believe there is a general policy in the police force on the behavior to adopt based on a driver’s past experience, although some individuals may modify their behavior in one direction or the other. This effect is implicitly considered a purely random effect in our analysis and should not have affected our results on the point-record incentives.

In this study, we have not examined the long-term evolution of accidents in detail, because we did not have access to the control variables of interest. In recent years, many road safety initiatives have had an impact on accidents but did not necessarily have any effect on violations. These initiatives include measures such as occasional campaigns to prevent fatal accidents, increased police patrols to reduce speeding, and designated-driver campaigns to prevent drinkers from getting behind the wheel. The decline in deaths and serious injuries can also be explained by vehicular improvements and the wearing of seat belts. All such measures are complementary to those studied in this article.

REFERENCES


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