THE HAMILTON PROJECT
Advancing Opportunity, Prosperity and Growth

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Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity

The Brookings Institution

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NOTE: This discussion paper is a proposal from the authors. As emphasized in The Hamilton Project's original strategy paper, the Project was designed in part to provide a forum for leading thinkers across the nation to put forward innovative and potentially important economic policy ideas that share the Project's broad goals of promoting economic growth, broad-based participation in growth, and economic security. The authors are invited to express their own ideas in discussion papers, whether or not the Project's staff or advisory council agrees with the specific proposals. This discussion paper is offered in that spirit.

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Abstract

The current lump-sum pricing of auto insurance is inefficient and inequitable. Drivers who are similar in other respects—age, gender, location, driving safety record—pay nearly the same premiums if they drive five thousand or fifty thousand miles a year. Just as an all-you-can-eat restaurant encourages more eating, all-you-can-drive insurance pricing encourages more driving. That means more accidents, congestion, carbon emissions, local pollution, and dependence on oil. This pricing system is inequitable because low-mileage drivers subsidize insurance costs for high-mileage drivers, and low-income people drive fewer miles on average.

In this discussion paper, we propose and evaluate a simple alternative: pay-as-you-drive (PAYD) auto insurance. If all motorists paid for accident insurance per mile rather than in a lump sum, they would have an extra incentive to drive less. We estimate driving would decline by 8 percent nationwide, netting society the equivalent of about $50 billion to $60 billion a year by reducing driving-related harms. This driving reduction would reduce carbon dioxide emissions by 2 percent and oil consumption by about 4 percent. To put it in perspective, it would take a $1-per-gallon increase in the gasoline tax to achieve the same reduction in driving. Unlike an increase in the gas tax, PAYD would save most drivers money regardless of where they live. We estimate almost two-thirds of households would pay less for auto insurance, with each of those households saving an average of $270 per car.

Despite the large social benefits from PAYD, there are currently several barriers to its widespread adoption, including the cost to monitor miles traveled and some state insurance regulations. In order to facilitate the spread of PAYD, we propose a three-part strategy. First, states should pass legislation permitting mileage-based insurance premiums. Second, the federal government should increase the funding available to PAYD pilot programs by $15 million over five years. Finally, since the monitoring costs may exceed the expected benefit of PAYD to insurance firms but are much smaller than the social benefit, the federal government should offer a $100 tax credit for each new mileage-based policy that an insurance company writes, to be phased out once 5 million vehicles nationwide are covered by PAYD policies. In short, PAYD represents a win-win policy. What is good for drivers, in this case, is also good for society.

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1. Overview

If you are like most Americans, you probably eat too much when you dine at an all-you-can-eat buffet. Now imagine that Americans paid for gasoline on an "all-you-can-drive" basis—paying a set fee each year for as much as they use. People would invariably drive more since there would be little cost to doing so. The idea may seem absurd, but that is how auto insurance is priced today. Drivers who are similar in all respects—age, gender, driving record—pay roughly the same premiums whether they drive five thousand or fifty thousand miles a year, even though the likelihood of being involved in a collision increases with each mile driven. (Some firms do offer a modest discount for driving below a certain number of miles, but even that is based on a self-reported estimate.) Moreover, just as people consume more food when they do not bear the cost of extra food, so too do they drive more when they do not bear the cost of insurance for the additional miles driven. The increased driving that results imposes significant costs on society: more traffic accidents, increased congestion, decreased air quality, growing greenhouse gas (GHG) emissions, and deepening dependence on oil. The current system is also inequitable, because low-mileage drivers subsidize the accident costs of high-mileage drivers, and low-income people drive fewer miles on average.

A better approach is simple and obvious: pay-as-you-drive (PAYD) auto insurance. With PAYD, insurance premiums would be priced per mile driven. Pricing insurance per mile is more equitable because low-mileage drivers would no longer subsidize high-mileage drivers. With insurance costs that vary with miles driven, people would be able to save money by reducing their driving, and this incentive would lead to decreased driving-related externalities like carbon emissions and congestion. PAYD is a simple and pragmatic reform. Moreover, it is more politically feasible than alternatives like a gas tax because PAYD does not increase the cost of driving in the aggregate. It saves money for those who drive less than average, shifting the cost to those who drive more and who thus are responsible for more accidents. Geography is already a key risk factor in pricing insurance, so those in rural areas where people drive greater distances will not be disproportionately impacted because their premiums will be determined relative to how many miles the average driver in their area drives.

With insurance costs that vary with miles driven, we estimate that drivers nationwide would reduce miles traveled by about 8 percent. To put that in perspective, it would take a $1-per-gallon increase in the gas tax to achieve an equivalent reduction in vehicle miles traveled (VMT). An 8 percent reduction in VMT would yield net social benefits of $50 billion to $60 billion per year, largely from reduced congestion and accidents. It also would reduce carbon emissions by 2 percent and oil consumption by around 4 percent. In addition, PAYD can achieve these gains while actually *reducing* the cost of driving for most drivers. Almost two-thirds of households would enjoy reduced premiums under PAYD, and the average savings for those two-thirds of households would be $270 per car a year, equal to 28 percent of the average annual U.S. car insurance premium.

Despite the large social benefits from PAYD, there are currently several barriers to its widespread adoption. For one, insurance companies would incur costs to monitor miles traveled and develop new pricing models whereas most of the benefits would accrue to other insurance companies and society as a whole. In addition, insurance regulations in many states prohibit or pose significant barriers to pricing insurance by the mile.

In order to overcome these barriers and facilitate the spread of PAYD, we propose a three-part strategy. First, states should pass legislation permitting mileage-based insurance premiums. Second, the federal government should increase the funding available to PAYD pilot programs to $15 million over five years. Finally, the federal government should offer a $100 tax credit for each new mileage-based policy that an insurance company writes, to be phased out once 5 million vehicles nationwide are covered by PAYD policies.

2. The Challenge

Ever since Henry Ford made cars affordable to the masses, Americans have had a love affair with their automobiles. We run our cars almost 3 trillion miles a year, using 140 billion gallons of gasoline in the process. Currently, car owners pay roughly the same in automobile insurance regardless of how many miles they drive. To be sure, some companies offer a discount if a driver drives below a certain number of miles. For example, Liberty Mutual and State Farm offer a discount of about 15 percent if a driver drives less than 7,500 miles annually, but even that discount is based on a self-reported estimate, which limits the amount of discount offered.[1] There is no reliable method to verify the number of miles driven or adjust premiums accordingly. Progressive, one of the nation's largest auto insurers, explains as follows: "A principal problem with . . . conventional insurance determination systems is that much of the data gathered from the applicant is not verifiable, and even existing public records contain only minimal information, much of which has little relevance towards an assessment of the likelihood of a claim subsequently occurring."[2]

With this pricing scheme, there is almost no marginal insurance cost to driving another mile, yet the likelihood that a driver will be involved in a collision necessarily increases with mileage driven.[3] For example, as seen in Figure 1, a vehicle that travels twenty thousand miles is roughly twice as likely to have an accident as one that travels less than five thousand miles. As Nobel Prize–winning economist William Vickrey puts it, "The manner in which [auto insurance] premiums are computed and paid fails miserably to bring home to the automobile user the costs he imposes in a manner that will appropriately influence his decisions" (Vickrey 1968).

Notably, the relationship between VMT and accidents is not proportional. In aggregate, motorists that drive more tend to have fewer accidents per mile. One who drives thirty thousand miles a year will be involved in fewer than three collisions per million miles driven, whereas one who drives fewer than eight thousand miles a year will be involved on average in more than seven collisions per million miles driven (Figure 2).

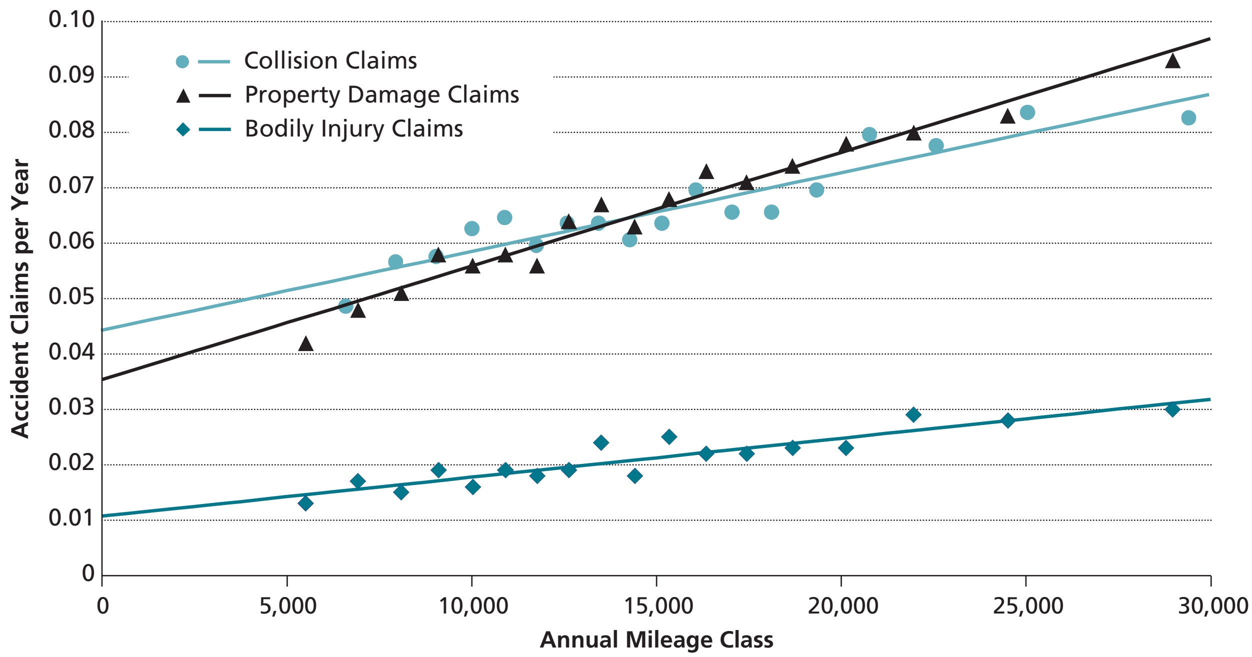
Some reasons the relationship is not proportional include the following (Litman 2005):

- Higher-mileage drivers tend to be more skilled than lower-mileage drivers.
- Newer (thus, mechanically safer) vehicles tend to be driven more.
- Urban drivers tend to have higher crash rates and lower annual mileage.
- High-mileage drivers tend to do a greater share of driving on safer, grade-separated highways.

While a comparison across different vehicles does not yield a proportional relationship, it is important to bear in mind that the risk of any individual vehicle being involved in an accident necessarily declines roughly proportionally with a reduction in VMT. Thus, while a high-mileage motorist may be only twice as likely to have an accident as a low-mileage motorist who drives one-fourth as much,

1. Liberty Mutual offers a discount in forty-five states plus the District of Columbia of between 5 and 18 percent to drivers who drive less than 7,500 miles per year. Most of these states offer a 13 percent discount. State Farm considers those who drive less than 7,500 miles a year to be low-annual-mileage drivers, and they receive a 15 percent discount on average. Geico also offers a discount to those who drive less than 7,500; the average amount of the discount was unavailable to us, however.
2. U.S. Patent No. 6,868,386 (filed May 15, 2000).
3. Of course, insurance premiums are not completely outside a driver's control: they do in some sense respond to mileage. Someone considering whether to drive another mile knows there is a chance she may get into an accident or be cited for a moving violation and thereby cause her insurance rates to jump in subsequent years. But given that the average driver has an accident every twenty years or two hundred thousand miles or so, this incentive does little on the margin (Insurance Information Institute n.d.).

FIGURE 1
Yearly Accident Claims by Annual Mileage



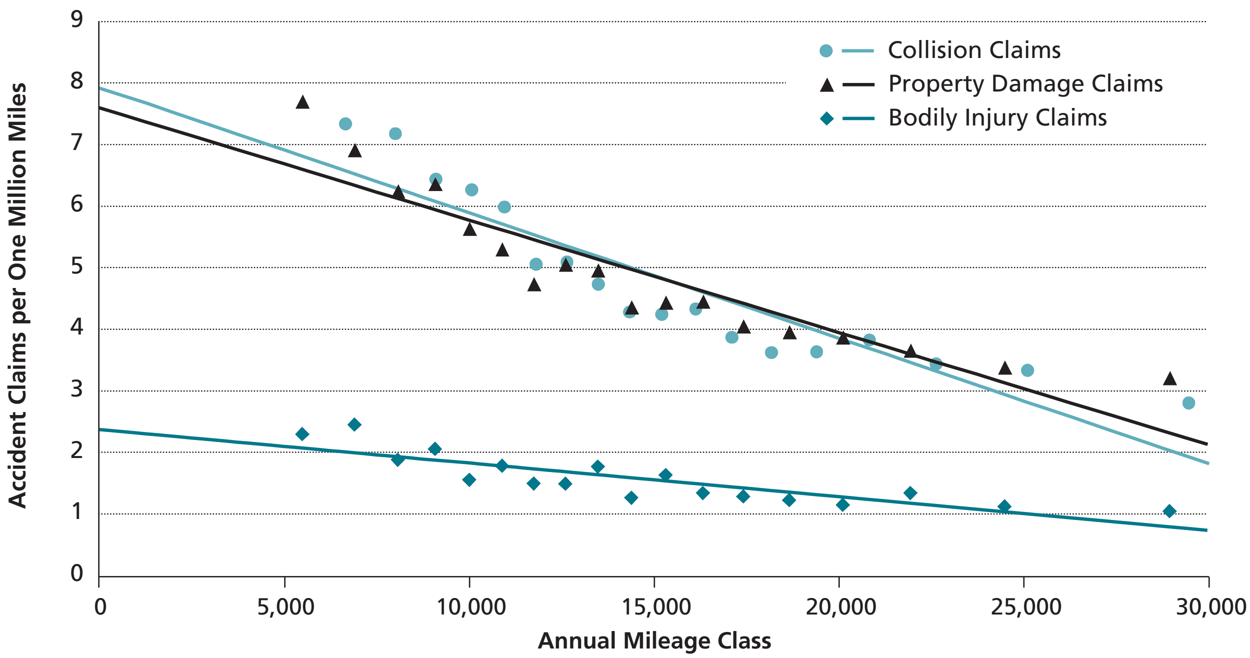
Source: Progressive 2005.

if the high-mileage driver reduces her VMT by 10 percent she will also reduce her risk of getting into an accident by about 10 percent. That relationship is likely to be proportional because the individual driver's attributes do not change if she drives less. Reliable data on individual VMT variations and accidents to confirm this proportional relationship for individual drivers are lacking because insurance companies generally do not make accident data publicly available. Unlike snapshot comparisons of vehicles across the distribution of VMT (such as in Figure 1), however, a better way to answer this question is to look at accident decline overall when there is an aggregate drop in VMT for all vehicles due to exogenous factors. For example, a recession in 1981–82 caused a 10 percent reduction in VMT and a 12 percent reduction in insurance claims in British Columbia (Litman 2005), which is a more-than-proportional decline.

While insurance companies do not price auto insurance based on miles driven, they do use other risk information as proxies. Their current pricing structure is thus already picking up some of the mileage differences between drivers. Companies may indirectly capture mileage risk, for example, by charging drivers who say they live far from work and who have poor accident histories a higher premium than they charge those with the opposite characteristics. This does not mean actual mileage should not be taken into account, however. Pricing per mile would still be a far more accurate way to price based on risk than using such proxies, particularly given that accidents necessarily and evidently (Figure 1) increase with mileage. A motorist's driving record also is not an adequate proxy since the likelihood of having an accident is so low; neither a low-mileage driver nor a high-mileage driver may thus have been in an accident, even though the likelihood of the high-mileage driver being in one is still several times higher. Indeed, in interviews we conducted with insurance companies and their actuaries, there was consistent agreement that charging for mileage would be preferable to the current system. One

FIGURE 2

Accident Claims per Million Miles by Annual Mileage



Source: Authors' calculation based on Progressive 2005.

company executive called charging per mile the "last barrier of insurance pricing."

Fundamentally, the pricing structure of auto insurance has not changed since Vickrey's observations forty years ago. In 1968, he wrote the following:

> The basic difficulty is that the insurance premium appears to the individual automobile owner almost entirely as part of the fixed cost of owning a car. The amount of the premium, given the coverage he selects, is fixed by factors largely independent of most of the decisions that are at all marginal as to how much he will use his car. The only attempts that are made to vary premiums in relation to use are typically to classify the risk according to whether and how far the car is driven to work or whether it is used for business; the classifications are very broad and to a considerable extent are based on the unverified statements of the applicant. Moreover, the variations in premiums based on such classifications remain relatively small. The result is that with the possible exceptions of the decisions as to whether to drive to work or use public transportation, and of the decision as to whether younger members of the family are allowed to drive at all, the added exposure to risk involved in added usage is not brought to bear on the decision. (Vickrey 1968, 470–71)

There are two problems with the current lump-sum pricing structure. First, low-mileage drivers end up subsidizing high-mileage drivers in each risk class, even though the former are responsible for fewer accidents. This problem is particularly disturbing given that low-income people tend to drive less on average (Figure 3). In 2001, households with incomes above $100,000 drove each of their vehicles on average 25 percent more miles than households with incomes below $25,000. Recent survey data from the Greater Vancouver Regional District show an even stronger correlation (Litman 2007b).

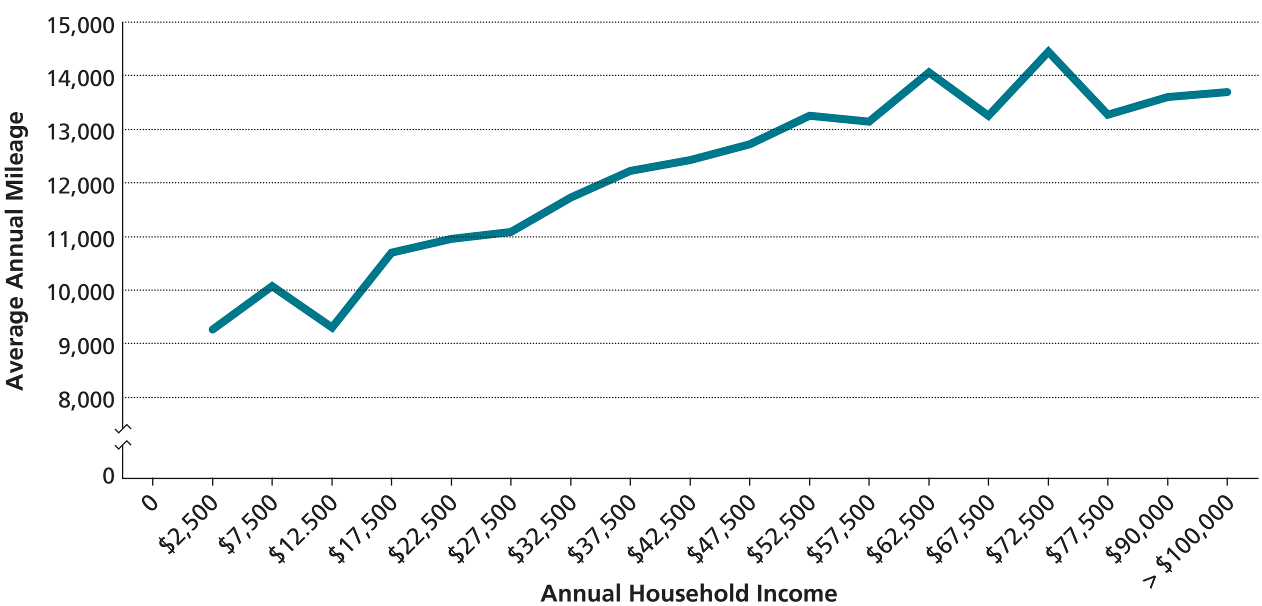
Second, lump-sum pricing leads to an inefficiently high level of driving and thus makes drivers worse off. Since insurance is priced in a lump-sum fashion, a driver does not take the marginal cost of insurance into consideration when deciding how much to drive (the way she might consider the costs of fuel and maintenance, for example). The result is that some of the miles she drives are not worth the marginal cost to her if she were actually to pay for insurance per mile driven. If she could pay for insurance by the mile and save that cost by reducing miles driven, she would do so and be better off by paying lower total premiums. PAYD makes this possible. A driver only needs accident-related car insurance when she is driving. But unlike for almost every other good available to consumers, under the current system a driver cannot pay less for car insurance by consuming less of it.

The result of this inefficient pricing structure, as Vickrey (1968) explained, is an increased number of VMT, and all these extra miles also impose significant costs on society. Burning fossil fuels in vehicles releases carbon dioxide (CO_2), a heat-trapping gas that can remain in the atmosphere for more than a hundred years. CO_2 is the principal GHG responsible for global warming, a human-caused process that is now widely accepted as real. This warming may cause massive climatic shifts, characterized by changes in precipitation and runoff, increased flooding, drought, and more-frequent and severe storms. Continuing to burn such high quantities of fossil fuels could trigger climate change costing the economy up to 1.5 percent of GDP (Cazorla and Toman 2000).

Increased gasoline use also deepens our nation's reliance on oil, increasingly understood as a threat to economic and national security. Oil price shocks have played a role in nine of the ten U.S. reces-

FIGURE 3

Average Mileage per Vehicle, by Household Income Level



Source: Authors' calculation based on data from the 2001 National Household Transportation Survey.

sions since World War II. Oil wealth strengthens oil-exporting authoritarian governments and limits America's foreign policy options for meeting their growing threats. Reducing oil consumption is the key factor in improving America's energy security.

Every additional mile driven also adds gases to the atmosphere that contaminate the air we breathe. Nitrogen oxides (NO_X) and hydrocarbons (HC) have serious and negative impacts on human health.

Even greater than these environmental and security concerns is the estimated impact of increased driving on traffic congestion. Urban traffic congestion in 2005 caused the average peak-period traveler to spend thirty-eight extra hours in travel time (Schrank and Lomax 2007). The number of urban areas with more than forty hours of annual delay per peak traveler has grown from only one in 1982 to twenty-eight in 2005. This wasted time costs the country $78 billion annually, which is almost exactly the size of the entire U.S. federal transportation budget.

Finally, more driving increases the number of auto accidents. Even when a driver is not at fault, merely being on the road increases the likelihood of an accident because there is one more car with which another car could potentially collide. Thus, even adding the safest of drivers to the road increases total accident costs because there are more cars on the road. Economist Aaron Edlin (2003) finds that the elasticity of accidents with respect to VMT may be around 1.7, meaning that a 10 percent reduction in VMT would lead to a 17 percent reduction in total crashes. The costs of accidents—in terms of lives lost, injuries to victims, lost productivity, property damages, medical costs, travel delays, and legal expenses—are staggering. Ian Parry, Margaret Walls, and Winston Harrington (2007) estimate that accidents cost the United States $433 billion in 2000.

To be clear, PAYD would not address these driving-related externalities in full by forcing drivers to internalize the cost of the social harm caused by their activities. Doing so would require a set of optimized user fees specifically calibrated to capture each externality. By reforming the way auto insurance is priced, however, PAYD also begins to make progress on all these issues by creating an incentive to reduce driving. PAYD is a politically viable way to make progress on all these issues because it actually reduces the cost of driving for most people.

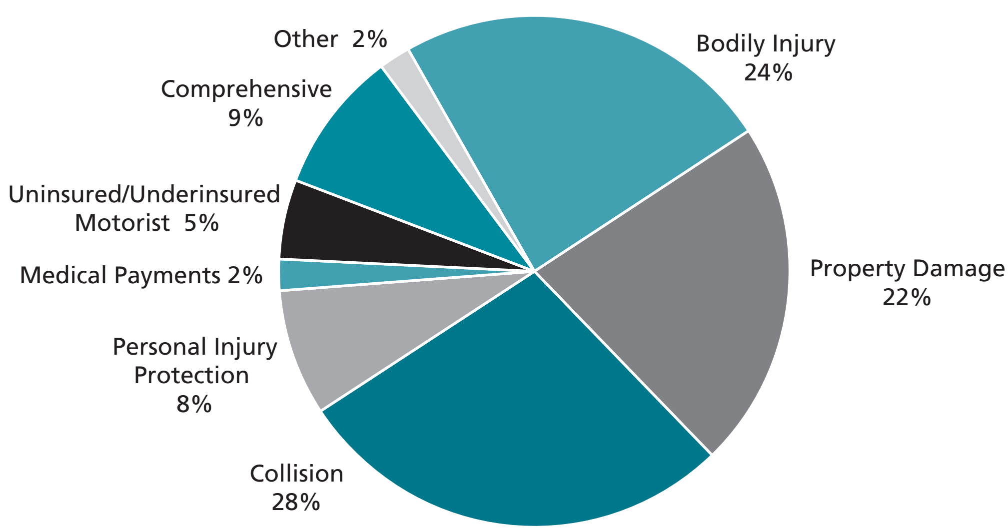
3. A New Approach

A relatively simple and pragmatic way to address the problems with the way auto insurance is priced also would help reduce all these driving-related externalities. Under PAYD auto insurance, the price of auto insurance would be tied to the number of miles driven. Other rating factors such as location, age, vehicle type, and driving record still would be incorporated into this price, so higher-risk drivers would pay more per mile than lower-risk drivers. PAYD ensures that low-mileage drivers stop subsidizing the accident costs of high-mileage drivers. By allowing people to save money by driving less, PAYD creates incentives for reducing the various costs that driving imposes on society.

A small portion of current premiums cover risks not directly related to mileage, so they would remain unchanged. This includes, most prominently, comprehensive coverage, which covers damage caused by fire, theft, vandalism, and weather. The majority of car insurance premiums cover risks that vary directly with mileage; these premiums thus would be switched to a per-mile rate. These include liability coverage (for the costs of bodily injury and property damage imposed on others when the insured causes an accident); collision or accident coverage (for medical payments, personal injury costs, and collision damages incurred by the insured and her vehicle when the insured causes an accident); and uninsured motorist coverage (for damages to the insured and her vehicle caused by an uninsured motorist). According to personal email communication with Progressive County Mutual Insurance Company, liability, accident, and uninsured coverage make up 89 percent of the typical premium it collects (Figure 4).

FIGURE 4

Distribution of Progressive Auto Insurance Premium, by Type of Coverage



Source: Personal e-mail communication with Progressive, 5/14/08.

A. Designing PAYD Insurance

There are several specific design features firms will need to choose. Under the simplest model, motorists would prepay for the miles they expect to drive in a year and then pay more or receive a refund at the end of the year depending on actual miles driven. In order to avoid people purposely underestimating to defer payments, firms might automatically set each year's estimate at the total number of miles driven in the prior year. Drivers would be free to change that estimate if they anticipated driving more or less than the prior year, but might pay a penalty if the actual miles driven exceeded the estimate by more than a certain amount (say, 20 percent). Alternatively, insurance companies could bill motorists based on their monthly or bimonthly vehicle mileage, just as utilities currently do. This would require more-frequent mileage data collection, however, probably via a telematic device in the vehicle. Though more costly, this approach may result in larger social benefits by effecting a larger reduction in VMT, as discussed further below.

PAYD requires verified mileage data. One way to do that is through odometer audits. Licensed professionals such as safety and emissions inspectors could verify mileage every year, or even more frequently. They would have to ensure the odometer was not tampered with and then transmit the data to insurance companies. Drivers would bear the cost of taking their cars in to be checked, though in some states and many urban areas annual inspections are already required at which an odometer reading could be done (in some cases this is being done now). Currently, nine states have mandatory annual inspections for all vehicles, four states have mandatory inspections for all vehicles every two years, and various localities in nine other states have mandatory inspections every one or two years. One company, CARFAX, claims to aggregate all these various publicly available odometer readings into its vehicle history reports, available to insurance companies on any car and light truck model 1981 or later. Individual consumers can have unlimited access to vehicle history reports for one month for $29.99, but commercial rates vary by volume and purpose.

Another option is to use electronic devices that automatically record and transmit mileage data. Most new cars already electronically record mileage in the engine computer, and new technologies such as global positioning system (GPS) transponders provide a means of wireless transmission. Table 1 describes several technology options available to insurers. Davis, an American company based in California, offers its CarChipPro technology to individual consumers for $119. The CarChipPro is a small data-collection device that plugs in to a car's on-board diagnostics (OBD) port, reading and storing data from the car's on-board computers. (OBD ports have been mandatory for new cars in all states since 1996.) Consumers connect the small device to their home computers via a USB cable to download driving data. A wireless version is available, tailored to fleet managers, which allows for wireless transmission of the data when a vehicle is parked near a receiving transponder. Other versions of similar technology are available from companies such as IMS and Sky-meter. Both these firms market specifically to insurance companies and offer wireless data transmission. The device from Sky-meter is leased to the consumer (or company) for a $5 monthly fee plus a portion of the insurance premium. Conversations with auto insurance executives and manufacturers reveal prices have been declining and are expected to continue declining significantly as the technology advances. Most of these devices do not record or transmit information about a driver's location, and even those devices that have such a capacity may be tailored to eliminate any privacy concerns.

TABLE 1

Cost of Commercially Available Telematic Mileage-Recording Devices

Manufacturer	Data recorded: Distance, speed, time	Method of transmission	Installation cost	Monthly/yearly fee
Davis				
CarChipPro	Distance, speed, time (could include other features for higher price)	USB cable/port (customer loaded)	$119	None
CarChipFleetPro	Distance, speed, time (could include other features)	USB cable/port (customer loaded)	$169 (plus a $395 charge for software, one per fleet) Can also be used wirelessly with a $200 base unit	None
IMS iPAID	Distance, speed, time	USB cable (manual upload on PC) or Bluetooth (automatic upload) or cellular (GPRS)	$60–$80 for mileage measurement only	Varies
Sky-meter	Distance, speed, time (incl. other features)	GPRS/CDMA (other protocols available at extra charge)	$50 - $250 activation fee	$5 per month plus 5%–8% of monthly premium (depending on volume)
OnStar	Distance, speed, time, (incl. other features)	Automatic through GPS	First year free for new GM cars (only available for GM)	$18.95 per month after one year

Source: Company Web sites and personal communications with authors.

Other models of monitoring mileage exist. For example, one is being developed by start-up insurance firm MileMeter. Under its model, individuals would go online and purchase a specific number of miles of coverage. A driver would not be covered in the event of an accident if the car's odometer indicated that the driver had exceeded the amount of insurance purchased. This approach negates the need for odometer audits, though it may raise concerns about uninsured cars. MileMeter would still collect odometer readings from vehicle emissions, maintenance, and registration databases (similar to the information available from CARFAX).

Some established companies are already using monitoring technology to offer mileage discounts on insurance premiums. In June 2008, Progressive announced a national rollout of its MyRate insurance program. Under MyRate, cars driven less often, in less-risky ways, and at less-risky times of day can receive a lower premium (Progressive 2008). According to Progressive, the impact on premiums could be anywhere from a 60 percent discount to a 9 percent surcharge. The MyRate program evolved out of Progressive's TripSense program in Michigan, Minnesota, and Oregon. Under that program, participating drivers receive a TripSensor based on the Davis CarChip technology. The TripSensor records how much, how fast, and when the vehicle is driven—information that is used to calculate discounts of 5–20 percent when the customer renews the policy. (This program is thus not true per-mile pricing.) The collected data and the potential discount are communicated to the customer before they are shared with Progressive. The customer has the option of sharing the information with Progressive and earning the discount or withholding the data and paying the normal premium.

General Motors Acceptance Corporation (GMAC) Insurance has offered mileage-based discounts to OnStar subscribers located in certain states; drivers in thirty-four states are currently eligible. The system reports the odometer reading at the beginning and end of the policy term, and the customer receives discounts on a sliding scale for driving less than fifteen thousand miles: 1–2,500 miles (50 percent discount), 2,501–5,000 (33 percent), 5,001–7,500 (28 percent), 7,501–10,000 (20 percent), 10,001–12,500 (11 percent), and 12,501–15,000 (5 percent). GMAC currently has about twenty-five thousand OnStar subscribers, some of whom are signed up for the mileage discount. OnStar is free for the first year for new GM car owners, but costs $18.95 per month subsequently.

While the precise manner in which PAYD insurance is implemented may vary, how the pricing is designed can have a significant impact on the extent to which PAYD reduces VMT. Insights from behavioral economics about loss aversion, for example, teach us that consumers would prefer to avoid a surcharge than to receive a discount (Kahneman, Knetsch, and Thaler 1986). PAYD would thus be more likely to result in a greater reduction in VMT if drivers were charged an insurance price for each mile driven than if they were to receive discounts for driving fewer miles than expected.

In addition, the frequency with which the cost of insurance is communicated to drivers and the clarity and simplicity with which that cost is communicated will affect how much drivers change their behavior. To be clear, the goal of PAYD pricing should not be to maximize driving reductions at all cost, but rather to send accurate and consistent price signals to consumers, enabling them to make individually optimal decisions. Economist Amy Finkelstein recently found that when tolls switch from cash payments to electronic toll collection, toll prices increase more sharply. She also finds that the short-run elasticity of driving with respect to the actual toll declines after electronic tolls are introduced. After rejecting various other possible explanations, she concludes the most likely reason is that it is easier for toll collectors to raise prices when drivers are less aware of the price they are paying (Finkelstein 2007). This phenomenon also can be seen in recent anecdotal evidence that hybrid car drivers alter their driving behavior to maximize fuel economy in response to real-time information about how many miles they are getting per gallon, as Michael S. Rosenwald points out in the *Washington Post* ("For Hybrid Drivers, Every Trip Is a Race for Fuel Efficiency," May 26, 2008). The lesson for PAYD would be that a driver is more likely to reduce VMT if she receives frequent price signals about the cost of her insurance than if she receives an insurance bill at the end of the year based on annual VMT, such as after an annual odometer reading.

B. Why PAYD Has Not Spread More Widely on its Own

If PAYD is more efficient and equitable, why is it not already offered? There are three market and regulatory failures that prevent PAYD from emerging on its own: monitoring costs, state insurance regulations, and patents.

i. Monitoring costs.

First, the monitoring costs borne by insurers may exceed the private benefits to firms, even though the private benefits are far less than the potential social benefits (see Edlin 2003; Rea 1992; Williamson, Olson, and Ralston 1967). In order to price insurance per mile, insurance firms or their customers would need to incur the cost of verifying mileage, either through odometer checks (fitted with tamper proof technology) or through a device fitted in each vehicle. Though in theory odometer readings could be inexpensive procedures if done on a widespread basis, there currently is no infrastructure of certified providers to provide reliable odometer readings that insurance firms can use. Without the ability to rely on the accuracy of a service station's odometer reading, firms would have to employ their own teams of odometer readers, which might be cost prohibitive. They also would have to compensate customers somehow for their time if they were not able to combine the odometer reading with normal inspections or maintenance work. Installing GPS or similar technology to monitor VMT might be expensive. As seen in Table 1, it can cost well over $100 just to install a device that records VMT, and can cost several times that amount, including monthly service fees, for a device that also wirelessly transmits the information to the company. These monitoring costs are borne by firms and their customers, but the benefits spill over to other insurance companies, other drivers, and society as a whole. If an insurance company is able to reduce the driving of its insureds, substantial savings will accrue to other insurance companies too, insofar as their insureds are less likely to be involved in accidents if fewer vehicles are on the road. Reduced driving benefits all other drivers also, via reduced congestion. Finally, savings will accrue to society as a whole from reductions in local and global pollution and oil dependence.

Despite the substantial social savings from switching to per-mile auto insurance, there may be very little direct savings that actually accrue to insurance companies. We calculate in §4 that if insurance companies captured all the benefit from reduced accidents of their insureds they would save $34 per year per vehicle that switched from traditional lump-sum premiums to PAYD. We also calculate that the average low-mileage driver might save as much as $318 per vehicle as PAYD eliminates the implicit subsidy to high-mileage drivers. Those savings would be offset in aggregate by higher premiums charged to high-mileage drivers, but in the short term it might be possible for first-mover auto insurers to capture some of these gains by signing up low-mileage drivers currently with other insurers. In the long run, any private gain would likely be much lower since expected benefits would be competed away once other firms also adopt PAYD. Moreover, it may be difficult for insurance firms to capture fully these gains from any particular customer, given the high churn rate for customers in the auto industry. To capture that return from new or existing customers the firm must develop a new billing and administrative infrastructure, retool their advertising to educate consumers, and develop new actuarial models to determine how to price per-mile premiums, all of which would add to the cost.

The private incentive pales in comparison to the social benefit from switching a vehicle to PAYD, which we calculate in §4 to be $257 per vehicle. In other words, there are large positive externalities arising from PAYD that cannot be captured by private firms offering it. The significant discrepancy between the social and private benefits suggests that even if the benefits to the firm and its insureds do not justify an insurance company's incurring the monitoring and plan development costs, the full social benefits would justify the costs.

ii. State insurance regulations.

Second, state insurance regulations can pose a barrier to PAYD. State regulators must explicitly approve the type of insurance policies that insurers can offer; in several states, current regulations appear to prohibit pricing insurance per mile. Current efforts to permit PAYD pricing in California are indicative of the types of barriers that PAYD faces due to various state laws and regulations. Proposition 103 requires that automobile insurance premiums be based primarily on three factors in descending order of importance: (1) driving safety record, (2) annual miles driven, and (3) years of driving experience. Despite this law's intention to ensure that mileage be taken into strong consideration, the regulations that implement it may actually stand in the way of offering true PAYD pricing. Insurance firms in California typically offer only very wide mileage bands because they must accept self-reported estimates of miles driven. As a result, low-mileage drivers are paying too much for auto insurance and are subsidizing high-mileage drivers. The regulations implementing Proposition 103, however, prohibit an insurance firm from charging a PAYD customer whose VMT was verified a lower premium than a customer of identical risk profile whose VMT was not. These implementing regulations thus preclude offering an insurance product to low-mileage drivers that more accurately reflects their accident risk because other low-mile drivers in traditional insurance plans would be paying a different (and higher) rate. Currently, the California Department of Insurance has undertaken a rulemaking process, and a bill is pending in the state Senate (AB 2800), both of which are aimed at overcoming such obstacles to offering PAYD in California.

A 2002 survey by the Georgia Institute of Technology of forty-three state insurance commissioners found that 37 percent indicated state regulations would not permit PAYD insurance in their state (Guensler, Amekudzi, Williams, Mergelsberg, and Ogle 2002).[4] Even in states in which regulation does not explicitly prohibit PAYD, certain legislative reforms might be needed because of potential conflicts with existing law. Michigan, for example, requires an upfront statement of the premium charge, and the policy must have an expiration date and must be renewable. This might be difficult under PAYD since the total premium for any period is unknown at the start of the period (although a program could theoretically be designed to charge a fixed up-front cost and then offer per-mile discounts based on miles actually traveled). In Georgia, companies need to ensure that their policy requires a down payment for at least sixty days of coverage and that the minimum insurance term was not less than six months, but such temporal requirements might be inconsistent with certain per-mile pricing models. Until the law was modified in 2001, the Texas Transportation Code required proof of insurance (for vehicle title changes) to be a one-month policy, which a PAYD policy would not satisfy; presumably several other states may have a similar regulatory obstacle to PAYD.

Even in states that permit PAYD in theory, several insurance commissioners indicated that regulations in their state would prohibit certain commonly proposed methods of pricing PAYD. Roughly half of the states responding would not permit a PAYD pricing model whereby premiums would be based on the driver's current annual fees and reported mileage (Guensler et al. 2002). The survey respondent in Tennessee, for example, indicated the state would not accept such a pricing method because the structure constituted a retrospective rating scheme, which its regulations do not allow. In West Virginia, the regulations require that customers be insured at all times, and PAYD might mean that drivers would

4. This survey is several years old and was imprecise in its design, thus its findings should be viewed with considerable caution. Nonetheless, it is instructive of the types of regulatory barriers PAYD faces.

lose coverage if they exceeded the prepaid number of miles (although an insurer could structure a PAYD program to ensure that participating drivers are never uninsured).

Furthermore, auto insurance agencies must have their rate plans approved by state regulators each year. Whereas regulators typically approve as a routine matter current rate plans submitted for reapproval, they closely scrutinize changes to rate plans. In interviews, insurance firms argue that they are thus reluctant to attract extra scrutiny from regulators by offering innovative products. Insurance regulators whose primary charge is to ensure that insurance consumers are not harmed may be reluctant to approve a rate plan as revolutionary as PAYD, given such uncertainty about what the ultimate rate plans will look like. Regulators' reticence is likely exacerbated by the limited familiarity with PAYD and widespread misunderstandings regarding its effects. For example, the New York respondent to the aforementioned survey stated that cents-per-mile programs would not be equitable because upstate drivers tend to drive more than downstate drivers do (Guensler et al. 2002). (In practice, premiums are risk-adjusted, so upstate drivers would be charged more only if they drive more than the average similarly situated driver.)

Finally, the heavily regulated insurance field may pose barriers for new entrants, a concern confirmed by conversations with start-up firms in the industry. Established firms may be content with the status quo, notwithstanding its inequities and failings. Inertia, high start-up costs, and uncertainty may discourage them from adopting a radically new business model like PAYD. In well-functioning competitive markets, new entrants might promote such innovation at a more rapid pace. To the extent such competitive forces are blunted in the insurance sector, however, innovations like PAYD may be discouraged.

iii. Patents.

Finally, for the past decade Progressive has aggressively sought patents around innovations in telematic auto insurance (Tom Bakos Consulting and Markets, Patents and Alliances 2004).[5] Indeed, even the title "Pay As You Drive" is registered to Progressive, which precluded Unigard from using that title for its per-mile insurance product launched as part of a federally funded pilot program in King County, Washington. In interviews with the authors, several auto insurance executives have identified these patents as a barrier to adoption of PAYD insurance.

Progressive holds four patents related to PAYD, each of which is quite broad in scope. Three of these patents involve a "monitoring system for determining and communicating a cost of insurance."[6] A few of the most relevant claims include the following:

- "A method of determining a cost of automobile insurance for a selected period based upon monitoring, recording and communicating data representative of operator and vehicle driving characteristics during said period, whereby the cost is adjustable by relating the driving characteristics to predetermined safety standards."[7]

- "A process for acquiring and recording vehicle insurance related data during a time period via an on-board computer and recording system for adjusting an insurance cost during the time period."[8]

- "A method of insuring a vehicle operator for a se-

5. MileMeter also holds patents related to PAYD. We focus on Progressive's, however, since they are broadest in scope.
6. U.S. Patent No. 6,868,386 (filed May 15, 2000) is a continuation-in-part of U.S. Patent No. 6,064,970 (filed August 17, 1998), which is a continuation of U.S. Patent No. 5,797,134 (filed January 29, 1996). A continuation is a copy of an original patent application except the inventor adds new "claims," and a continuation-in-part is similar except that the inventor adds a description of the improvements to an invention and submits claims covering the improvements.
7. U.S. Patent No. 5,797,134 (filed January 29, 1996) (claim 1).
8. U.S. Patent No. 5,797,134 (filed January 29, 1996) (claim 12).

lected period based upon operator driving characteristics during the period."[9]

- "A system for Internet on-line communicating between an insurer and insured, of detected operating characteristics of a unit of risk for a selected period, as decided by the insurer in consideration of the detected operating characteristics."[10]

Additionally, Progressive holds a fourth patent, U.S. Patent 7,124,088 (filed July 30, 1999), which claims "[a]n on-line insurance policy service system" that comprises various specific design elements (claim 1).

Any insurance firm interested in offering per-mile insurance pricing understandably might be concerned that doing so would open it up to a possible patent infringement suit. Even if the firm believed it had developed a method of per-mile insurance pricing that did not violate the patent or that the patent was invalid, it might be deterred by the mere threat of a lawsuit from Progressive. Defending a patent infringement suit can be enormously expensive (Jaffe and Lerner 2004). As several recent studies have lamented, the sharp increase in the number of patents granted in the past two decades (including so-called bad patents that are overbroad or should not have been granted in the first place) has created high costs for firms and individuals that need to litigate patent lawsuits or pay unwarranted licensing fees, thus deterring the pursuit of pursuing new ventures (Jaffe and Lerner 2004; Lichtman 2006; Merrill, Levin, and Myers 2004).

Nonetheless, Progressive's PAYD patents may not be a serious barrier to PAYD adoption for three reasons. First, Progressive has expressed (in an interview with the authors) a willingness to license PAYD, although it is unclear to whom and on what terms. Second, there might exist several ways to design a PAYD system that does not infringe on Progressive's patents, an opinion expressed by several industry and patent experts. Indeed, several firms, such as GMAC, currently offer limited forms of mileage-based pricing without eliciting allegations of patent violation. Finally, there is a legitimate question about the extent to which Progressive's patents would be upheld in a patent infringement lawsuit, particularly in light of recent legal developments (Greenberg 2007). Of course, for any rival firm the legal process of challenging these patents' validity involves some risk and considerable expense, and thus acts as a significant deterrent itself, regardless of the eventual outcome.

Regarding the validity of Progressive's patents, a challenge could be brought in theory on "obviousness" grounds. To qualify for a patent, an invention must not have been "obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains" (35 U.S.C. §103(a) (2000)). Recently, the Supreme Court clarified the meaning of "obviousness," encouraging lower courts to be more open to the possibility that an issued patent might still in fact be invalid for obviousness.[11]

As a result, the Progressive patents may be vulnerable. Four decades ago, Vickrey (1968) observed that optimal auto insurance pricing should take account of VMT. "There is no real conceptual difficulty in charging an insurance premium according to mileage," he explained. "The problem is one of implementation" (Vickrey, 1968). There was thus a known problem with auto insurance pricing, and "[u]nder the correct analysis, any need or problem

9. U.S. Patent No. 6,064,970 (filed August 17, 1998), (claim 4).
10. U.S. Patent No. 6,868,386 (filed May 15, 2000), (claim 10).
11. *KSR Int'l Co. v. Teleflex Inc.*, *127 S. Ct. 1727 (2007)*. The issue in that case was a patent describing the combination of an adjustable pedal assembly with a pedal position sensor attached to the supporting shaft of the pedal assembly. Originally, adjustable pedal systems were designed to work in vehicles without computer-controlled engines. In the mid-1990s, however, the auto industry largely switched to computer-controlled engines that required electronic throttle controls. While the older systems relied on cables to link the pedal to the throttle, these new systems required the use of pedal position sensors to achieve the same interaction. KSR argued that Teleflex's patent was invalid because the combination of an adjustable pedal assembly and a pedal position sensor was "obvious."

known in the field of endeavor . . . can provide a reason for combining the elements in the manner claimed" (KSR, 127 S. Ct. at 1742). As GPS and other telematic systems became broadly available in automobiles, combining these devices with auto insurance to address the problem Vickrey identified may well be considered to have been obvious. Although GPS-type technology was often used for other purposes, such as tracking a vehicle's location, "familiar items may have obvious uses beyond their primary purposes, and in many cases a person of ordinary skill will be able to fit the teachings of multiple patents together like pieces of a puzzle" (KSR, 127 S. Ct. at 1742). As the Court explained, "[a] person of ordinary skill is also a person of ordinary creativity, not an automaton" (KSR, 127 S. Ct. at 1742). Moreover, the literature about how to price auto insurance more accurately to reflect driver risk is replete with references to a limited number of conceivable options: require manual odometer checks, add the cost of insurance to the price of gasoline purchased at the pump, or install devices in vehicles to track VMT. (A few additional ideas may be found here and there, such as Vickrey's theoretical suggestion to add the cost of insurance to the price of tires.) When there is an identified problem of the kind Vickrey observed, "there are a finite number of identified, predictable solutions, [so] a person of ordinary skill has good reason to pursue the known options within his or her technical grasp." If the result is success in solving the problem, "is it likely the product not of innovation but of ordinary skill and common sense. In that instance the fact that a combination was obvious to try might show that it was obvious under section 103" (KSR, 127 S. Ct. at 1742).

Like most legal issues, of course, there also are strong arguments on the other side as well. A full discussion of all these arguments is beyond the scope of this paper. The purpose of the above discussion is simply to indicate that a rival firm wishing to offer a PAYD product may still be able to do so despite existing patents.

4. A Three-Part Strategy to Encourage PAYD Adoption

It is hard to tell how significant each of the three barriers is by itself. The paucity of mileage-related insurance offerings and the nonexistence of true PAYD pricing, however, indicate the barriers together pose a real roadblock. Given the potential for significant social benefits from wide adoption of PAYD combined with the small expected private benefits for firms there is a clear rationale for effective public policy solutions. Policymakers should take the following three steps in response to these barriers to encourage PAYD adoption.

First, enact regulatory and legal reforms to promote PAYD. At a minimum, states, where necessary, should enact model legislation and regulatory guidance permitting PAYD. For example, legislation passed in Texas in 2001 gave insurers permission to offer cents-per-mile pricing for vehicle insurance. The bill also required insurance companies to separately track and report the claim losses and premium revenues for mileage-based and time-based premiums (Texas House Bill 45). Even in many states where PAYD is technically permissible it may be necessary for the legislature to enact legislation clarifying that PAYD is permitted in order to signal that insurance regulators will look favorably on PAYD rate submissions and reconcile potential conflicts with existing regulations that were written for lump-sum rate plans. As already discussed, in California, for example, a bill and rulemaking process is aimed at permitting insurance firms to vary per-mile premiums depending on whether the odometer readings are verified or self-reported.

While state regulatory action is needed, states may undervalue the importance of PAYD because some of the benefits, like energy security and climate change, are national (indeed, global). If state regulation continues to be a barrier to firms offering PAYD and states do not address the issue, the federal government should encourage states to act by conditioning the receipt of federal discretionary grants and formula allocations on the reform of state insurance regulations to permit PAYD.

Second, expand funding for PAYD pilot programs. There is a lack of knowledge on the part of insurance firms and state regulators about how to price and design PAYD, significant start-up costs involved with being a first mover, and barriers to potential entrants. Given the small private benefit but large social benefit from PAYD, a booster shot from the government may be needed for an insurance firm to offer it, which may then push other firms to follow suit. Such a pilot program would teach insurance firms, regulators, and the public about the feasibility and benefits of PAYD.

Currently, funding for PAYD pilot programs has come from the federal Value Pricing Pilot (VPP) program, authorized under the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), from federal funds distributed to states by formula, and from other government sources. The VPP program provides $12 million a year for pilots related to congestion pricing, innovative parking programs, PAYD, and other pricing strategies to reduce congestion. Of these funds, a minimum of $3 million a year must be used for pricing projects not involving tolls, such as PAYD. PAYD grants have ranged between $1 million to $2 million. In March 2007, King County, Washington was awarded $1.9 million in Federal Highway Administration (FHWA) discretionary funds for its PAYD pilot, which also received $1.2 million in state and local funds. Unigard, the winning bidder, is matching these grants, investing $3.3 million in the pilot. In 2006, Progressive was awarded $1.3 million in federal, state, and local funding for a mileage-based (but not true PAYD) pilot in North Central Texas. This study monitored the response of three thousand customers.

Congress should reauthorize the VPP when the SAFETEA-LU bill is up in 2009, and should add $3 million a year targeted solely to funding true PAYD pilot programs. A true PAYD insurance program is one where the unit of exposure is equal to one vehicle mile, and the total units are multiplied by the policy rate to produce the policy premium.[12] The new, targeted funding would be enough to support a new pilot in five to ten large metro areas over the life of the program, which we expect to last five years.

Third, address the market failure around monitoring costs. The government should require that odometer readings be performed as part of required safety and emissions inspections or by certifying vehicle service businesses in other states to perform odometer readings. Odometer audits are inexpensive and can be performed while the vehicle is undergoing other servicing (Litman 2007a). If these audits were performed along with traditional servicing, the time inconvenience to customers would be minimal. The trouble is that today there is no infrastructure in place to certify and regulate providers of odometer readings to ensure their credibility.

Still, even with these reforms, trying to read each vehicle's odometers in a verifiable manner may prove difficult. Technological options are more costly but are less burdensome on individuals because they obviate the need to bring vehicles for odometer readings. They are also likely to elicit a stronger behavioral response because the price signals would be sent more frequently to the driver, as discussed in §3 (A). Some technology options would allow risk-adjusted mileage pricing, based on features such as time of day, driving area, and driver actions related to speed, acceleration, and braking (though these may raise more privacy concerns). In addition to the technology costs, firms face high development costs associated with switching from lump-sum to per-mile premiums, whatever forms of mileage monitoring they choose.

Given that the monitoring costs may exceed the expected benefit of PAYD to insurance firms but are much smaller than the social benefit, government should respond to the classic market failure arising from PAYD's positive externalities by providing a temporary tax credit to any insurance company for each customer it signs up to a true per-mile premium. As discussed in §3 (B.i), monitoring costs can total well over $100, while the benefit to the firm is likely to be quite small. Thus, we would propose a $100 per-vehicle tax credit for each new true per-mile policy, which would be phased out once 5 million vehicles are covered by PAYD policies. Given that there are roughly 225 million light-duty vehicles (cars, vans, pickup trucks and SUVs) in the United States, the tax credit would be eliminated once 2 percent of all premiums were of the PAYD variety. The $100 tax credit would be available to any firm, although customers involved in a federally funded pilot program would not qualify. The tax credit could be tailored, in theory, to give private firms incentives to set up their programs in a manner likely to give the best information to consumers and elicit a reduction in VMT. For example, the credit could increase depending on how many times a year the customer is billed, or if the firm's monitoring technology informs the driver in real time about how his driving is affecting his premium.

We cap the credit at roughly 2 percent of all vehicles because we believe that while this new product needs a push, once PAYD is offered its dynamic effects on the market will quickly induce more and more drivers to adopt this form of insurance pricing. Presumably, the first 2 percent of customers signing up to PAYD policies will be low-risk, low-mileage drivers that have a financial incentive to do so. But once these drivers are out of the per-year risk pools, average annual accident costs for the remaining drivers will increase, thus so too will annual premiums, over time. This will give even more drivers a financial incentive to switch to PAYD, which will further increase costs for those remaining under traditional

12. Insurers would have the option of varying the policy rate by speed, time of day, or other information gathered about the exposure unit.

policies, leading a few more drivers to adopt PAYD. A virtuous circle will soon develop that leads nearly all drivers to opt for PAYD policies. Another benefit of this dynamic is that PAYD adoption should quickly grow without having to make PAYD mandatory. Customers will always have the option to keep their current premiums, but over time more and more drivers will have a financial incentive to switch to PAYD.

The roughly $515 million cost of both the pilot program expansion and tax credits is less than 1 percent of the annual social benefits expected from PAYD, to which we turn in the next section. Moreover, even this small amount of government spending would not require new revenue. As discussed in §5 (B iii), the federal government would save roughly $1.4 billion annually because fewer accidents would mean less Medicaid and Medicare payments to accident victims and less lost tax revenue from reduced productivity of incapacitated or fatally injured workers.

5. Impacts, Costs, and Benefits

The net social benefits if PAYD were universally adopted would be approximately $50 to $60 billion a year, mostly from reduced accidents and congestion, as well as from reduced local pollution, carbon emissions, and oil dependence. Insurance premiums would decline for almost two-thirds of drivers, since a minority of high-mileage drivers are responsible for the majority of miles driven. In this section, we discuss in more detail the expected social and individual benefits, and consider who might be harmed.

A. Estimating the National Impact of PAYD

Two previous studies have quantified the effect that a switch to per-mile premiums would have on driving and welfare. Edlin (2003) uses insurance premium data to calculate the average per-mile insurance premium in each state. He inserts per-mile premium estimates into a driving and accident model to predict driving reduction and accident savings state by state. Using data from the late 1990s, he estimates driving would decrease by about 10 percent nationally, resulting in up to $20.5 billion in benefits from reduced accidents and congestion (updated to 2007 dollars). Parry (2005) builds a general equilibrium model that simplifies the analysis by aggregating all consumers into one representative agent. He includes a more comprehensive set of driving externalities: carbon emissions, oil dependence, and local pollution, in addition to accidents and congestion. Parry uses gas price and fuel economy data from the first half of this decade and borrows Edlin's estimate of national average per-mile premiums. He finds that a switch to PAYD would decrease driving and fuel consumption by 9.1 percent, resulting in a $20.5 billion welfare gain (updated to 2007 dollars).

We extend the previous analyses by using data on vehicles, driving, and household characteristics from the 2001 National Household Transportation Survey (NHTS), which allows us to estimate the driving reduction and cost impact of PAYD at the vehicle and household levels. The national data set includes observations from 21,374 households with full information on annual mileage and fuel economy for each vehicle owned by that household. We assume PAYD is available for light-duty vehicles (cars, vans, pickup trucks, and SUVs). We ignore buses and heavy trucks because their insurance companies probably have more information about their mileage, and thus their premiums probably already closely reflect mileage. Light-duty vehicles were responsible for 92 percent of all vehicle miles in 2006 (U.S. Department of Transportation [DOT] 2006, Table VM-1). In total, 41,672 vehicles are included in our sample.

We combine the information on annual mileage and fuel economy from the NHTS data set with other driving-related data to calculate the expected driving reduction from PAYD. We follow Parry (2005) in modeling the driving response from PAYD. Drawing on gasoline and mileage demand elasticities from previous literature, Parry assumes per-mile insurance premiums as high as a vehicle's per-mile fuel costs would reduce that vehicle's mileage by 15 percent (for details, see appendix). As explained earlier, only the collision, liability, and uninsured motorist portions of auto insurance premiums would be expected to switch to per-mile rates. For state-level data on these rates, we use a more recent version of the data that Edlin (2003) analyzed from the National Association of Insurance Commissioners (2007, Tables 1 and 2).[13] In 2001, these portions of the premium accounted for 84 percent of average

13. In the NAIC tables, premiums for uninsured motorist coverage are included in liability premiums.

expenditures on car insurance nationwide, or $809 of the $964 average total premium (updated to 2007 dollars). We divide average annual 2001 premiums by the average annual mileage for a vehicle in that state (from the 2001 NHTS data) to generate average per-mile insurance premium estimates for each state. We adjust for inflation to generate estimated per-mile premiums in 2007. The $809 average premium comes to 6.6 cents per mile. The NHTS data report the census division instead of the state for vehicles in small states (to avoid identification of the household), so we report aggregate per-mile premiums for those states. Estimated per-mile premiums are reported in Table 2. We use pretax gasoline prices in 2007 by state from the Energy Information Agency (EIA) data series "Gasoline Prices by Formulation, Grade, Sales Type," and pretax diesel prices from EIA's series "No. 2 Diesel Fuel Prices–Sales to End Users."[14] State and federal tax rates are from *Petroleum Marketing Monthly*, EIA, Table EN1 ("Federal and State Motor Fuels Taxes"). We divide the per-gallon retail price of fuel by the fuel economy of each vehicle to get per-mile fuel cost for that vehicle. Combining the initial mileage for each vehicle as reported in the NHTS, the driving response to per-mile premiums from Parry (2005), the per-mile premiums and the per-mile fuel cost, we can estimate driving reductions for each vehicle in the sample. The results aggregated by state are reported in Table 2. We find a nationwide reduction in driving and fuel consumption of 8 percent among the vehicles we consider. There is significant variation from state to state. States with more accidents and higher premiums would see larger reductions: New Jersey would see 13.5 percent reductions, and New York would see 11.5 percent reductions. States with fewer accidents and lower premiums would see lower driving reductions: Iowa and Kansas each would see 6 percent reductions.

14. Data on fuel prices were only available for the first eleven months of 2007 at the time of our analysis.

TABLE 2

Driving Reduction and Accident Cost Savings from PAYD

	State or Division	Per-mile insurance premium (cents)	Driving reduction from PAYD (percent)	Initial traffic Density (vehicles per lane year)	External accident cost per mile at initial traffic density (cents)	External accident cost savings (millions of dollars)	Individual accident cost savings net of lost driving benefits (millions of dollars)
	Alabama	5.5	6.6	301,940	1	30	100
	Alaska	9.6	10.8	165,755	-0.8	-4	24
	Arizona	7	8.4	477,398	6.5	277	169
	Arkansas	5.4	6.4	163,206	-0.8	-16	52
	California	6.8	8	861,111	31.1	6,844	819
	Colorado	8.1	9.4	265,905	0.3	6	172
	Connecticut	8.1	9.9	700,527	18.7	482	117
	Florida	8	10.2	760,883	23	3,889	764
	Georgia	6.1	7.9	455,034	5.6	411	253
	Hawaii	9.9	11.6	1,080,433	52.9	506	53
	Illinois	6	7.2	366,883	2.6	161	213
	Indiana	5.5	6.7	357,550	2.3	90	121
	Iowa	5	5.9	133,405	-0.9	-15	42
	Kansas	5	5.9	105,642	-0.9	-14	41
	Kentucky	6	7.1	293,459	0.8	20	93
	Louisiana	7.6	9.1	354,446	2.3	71	144
	Maryland	6.6	8.2	824,781	28	1,086	140
	Massachusetts	8.7	10.7	727,705	20.6	986	236
	Michigan	6.4	7.4	406,986	3.9	243	228
	Minnesota	5.9	7.2	207,987	-0.5	-19	109
	Mississippi	5.5	6.4	268,104	0.4	6	67
	Missouri	5.5	6.7	262,098	0.3	5	115
	New Jersey	9.7	13.5	898,418	34.4	2,759	452
	New York	9.2	11.5	587,108	11.8	1,511	689
	North Carolina	5.3	6.3	465,909	6	323	154
	Ohio	6.1	7.2	418,592	4.2	278	222
	Oklahoma	5.6	6.6	207,857	-0.5	-15	84
	Oregon	6.9	7.7	267,497	0.3	5	87
	Pennsylvania	7.3	8.6	428,418	4.6	344	313
	South Carolina	5.7	7.2	360,012	2.4	70	94
	Tennessee	5.8	7	365,951	2.6	103	132
	Texas	6.2	7.4	365,717	2.6	362	500
	Utah	6.6	8.2	284,073	0.6	9	65
	Virginia	5.6	7.3	516,930	8.2	403	152
	Washington	7.5	8.3	324,775	1.5	53	162
	Wisconsin	5	5.7	251,425	0.1	0	77
Division 1: New England	New Hampshire Maine Rhode Island Vermont	5.9	7	366,308	2.6	66	86
Division 4: West North Central	Nebraska North Dakota South Dakota	4.6	5	67,972	-0.7	-12	39
Division 5: South Atlantic	Delaware D.C. West Virginia	7	8.5	364,145	2.5	57	93
Division 8: Mountain	Idaho Montana Nevada New Mexico Wyoming	7.2	8.3	164,244	-0.8	-52	231
	U.S. Total	**6.6**	**8**	**357,946**	**2.4**	**21,306**	**7,703**

Source: Authors' calculations.

Our estimated 8 percent reduction in driving and fuel consumption (assuming all light-duty vehicles switch to PAYD) is somewhat smaller than the previous estimates by Edlin (2003) and Parry (2005). This is primarily because fuel prices have increased since the earlier studies, meaning that the introduction of per-mile premiums today would have a smaller proportionate impact on marginal driving costs and thereby elicit a smaller consumer response. In 2007, the nationwide average retail gasoline price was $2.73 per gallon, or roughly 13.6 cents per mile. Per-mile premiums of 6.6 cents per mile would have increased marginal fuel and insurance cost by 48 percent in aggregate. By contrast, in 2001 (the year in which the original NHTS data we used was collected) average retail gasoline prices were $1.42 per gallon, or roughly 7.7 cents per mile, and insurance premiums averaged 5.7 cents per mile. At that rate, per-mile premiums would have increased marginal fuel and insurance cost by 77 percent in aggregate.

Our estimated 8 percent reduction in VMT is based on 2007 fuel prices, though fuel prices at the time of publication are significantly higher. While full price data are not available to run our analysis using true fuel prices as of summer 2008, a back-of-the-envelope calculation assuming a nationwide average premium of 6.6 cents and a nationwide retail price of fuel of $4 per gallon (20 cents per mile) would reduce our estimated reduction in VMT to between 5 and 6 percent. We use 2007 fuels prices because they are the latest comprehensive data available at the time of our analysis and because future oil prices are notoriously difficult to forecast, recent increases notwithstanding.[15]

Moreover, even if fuel prices remain at their 2008 levels, there is reason to believe the driving response may not be much lower than we estimate. The model for driving response that we and others use based on fuel price elasticities is only accurate so long as fuel prices remain a relatively constant fraction of total marginal driving costs, which also include the costs of time and vehicle wear and tear. But when fuel costs grow faster than these other costs, proportional changes in fuel costs will have greater impacts on total driving costs and thus would be expected to have proportionately greater impacts on driving. Indeed, a recent analysis by Kenneth Small and Kurt Van Dender (2007) specifically allowed for such a relationship and found that a 58 percent increase in fuel prices would increase the elasticity of VMT with respect to fuel prices by 44 percent. Since we are comparing per-mile premiums to fuel prices, the Small and Van Dender result implies we should adjust our elasticity upwards as fuel prices increase and become a larger fraction of total driving costs. If we assume the Small and Van Dender findings (based on fuel price changes from 2001 to early 2006) apply similarly to the fuel price change between 2007 and 2008, then the 47 percent increase in fuel prices from $2.73 to $4 per gallon would imply the elasticity we should use is 35 percent greater, or -0.2 instead of -0.15. Using this higher elasticity with a fuel price of $4 per gallon would only reduce our driving reduction estimate from 8 percent to about 7 percent.

There are other reasons to view all the estimates with caution. For one, our model assumes every driver in the same state faces the same per-mile premium. In reality, though, there would be significant variation in rates, just as there is today. Drivers and vehicles that insurance companies deem higher risk *per mile* will be charged a higher premium. For example, younger drivers, drivers of unsafe cars, and drivers with poor driving records will all probably face higher per-mile premiums than we assumed, whereas other drivers would face lower premiums. Since driving more seems to lead to increased driv-

15. The EIA predicts that average regular gas prices will be $4.23 in the fourth quarter of 2008 but that they will then decline and average $4.06 in 2009 (EIA 2008). Economists at the Dallas Federal Reserve Board are even more skeptical that oil prices will remain at current levels, writing that "Absent supply disruptions, it will be difficult to sustain oil prices above $100 (in 2008 dollars) over the next 10 years" (Brown, Virmani and Alm 2008). Conversely, Goldman Sachs analysts in May 2008 predicted oil prices reaching between $150 and $200 per barrel by 2010 (Murti, Singer, Koh, and della Vigna 2008). Similarly, economist Jeff Rubin at Canadian brokerage CIBC World Markets predicts oil prices reaching $200 per barrel by 2010 (Rubin 2008).

ing skill (see Figure 2), high-mileage drivers would tend to be in the low per-mile risk group. Then if high-mileage drivers were charged lower-than-average per-mile premiums because they are better drivers, whereas low-mileage drivers were charged higher than average per-mile premiums, our aggregate 8 percent driving reduction estimate would be biased upward. This upward bias occurs because those being charged the most per mile would be low-mileage drivers to begin with.

Second, we assume all drivers respond equally to a proportionate change in marginal driving costs. It is possible that low-income drivers are more sensitive to marginal price increases than high-income drivers. This also could lead our aggregate driving reduction estimate to be upward biased since, as we showed earlier, low-income drivers already drive less on average. Assuming a constant elasticity across all drivers also ignores significant heterogeneity in drivers' alternative transportation options. All else being equal, a driver in a metropolitan area with reliable public transit options is more likely to be able to reduce vehicle mileage than a driver in a rural area with fewer options.

Third, if PAYD were implemented nationwide, the ensuing fall in vehicle mileage would clear traffic from roads and thus reduce the likelihood of accidents for every mile driven. If insured accident costs fell, this should cause per-mile premiums to fall as well, mitigating a small fraction of the initial driving reduction response. Reduced congestion also would lower the time cost of driving and thus encourage more driving.

Fourth, we have followed Edlin (2003) and Parry (2005) in assuming no change in the number of drivers and vehicles. Because PAYD reduces the fixed cost of owning and driving a car by allowing consumers to pay less for insurance by driving less, though, it could result in more vehicle purchases. However, as Parry points out, mileage per car falls with PAYD so it is unclear whether vehicle demand would increase or decrease.

Despite these cautions which together imply an estimated 8 percent reduction in VMT may be overstated, and despite the fact that the effects of sweeping changes in pricing insurance nation-wide are inherently unknowable, limited real-world experience also suggests that PAYD would yield a reduction in driving of around 8 to 10 percent. The FHWA and the Minnesota Department of Transportation cosponsored a demonstration project to test how consumers would change their driving behavior under PAYD pricing. They monitored driving behavior of participants and gave each a per-mile insurance price of between 5 cents and 25 cents per mile based on their mileage levels during an initial pre-experimentation period. An analysis of the results performed by Cambridge Systematics (2006) found a total reduction in driving of 8 percent. Similarly, in a 2006 PAYD pilot program by Progressive Insurance in Texas, drivers who opted for PAYD drove 10 percent fewer miles (Progressive 2007). In that pilot, participants received $25 for every 5 percent fewer miles driven than expected, an average of 4 cents per mile, up to $350 a year.

One problem, however, is that the real-world experience is based on extremely small sample sizes. The Minnesota study involved only one hundred thirty households. In addition, it is difficult to generate real-world evidence about the effects of PAYD because, even in the few cases in which a program similar to PAYD has been offered, there is usually no reliable information about a driver's VMT prior to entering the program. Of the 3,014 volunteer participants in Progressive's pilot, only 93 had odometer reading data available from the previous year's emissions inspection.[16] Thus, both the economic estimates and real-world experience need to be viewed with a certain degree of caution.

16. A more-extensive follow-up analysis evaluating the response of all 3,014 participants in Progressive's pilot program in conjunction with the North Central Texas Council of Governments is to be released shortly.

B. National Benefits of PAYD

The benefits of reducing mileage and fuel consumption by anything around the 8 percent we predict are substantial. An 8 percent reduction in driving by light-duty vehicles (a 7.4 percent reduction in driving from all vehicles on the road) would decrease total vehicle mileage by 222 billion miles and fuel consumption by 11.2 billion gallons (based on driving and fuel consumption data from 2006, the most recent year of reported data). To understand the magnitude of PAYD's impact, consider that a 40-cent increase in the gas tax would be needed to reduce gasoline use by 8 percent, and a 99-cent increase would be needed to reduce driving by 8 percent.[17] (The tax needed to reduce VMT is more than twice that required to reduce gasoline use because roughly 60 percent of the reduction in gasoline use from a gas tax comes from increased fuel efficiency rather than a reduction in VMT [Parry and Small 2005].)

As Table 3 shows, an 8 percent reduction of driving and gasoline consumption would have significant benefits for society from reduced accident costs, congestion, local pollution, CO_2 emissions, and oil dependence.

TABLE 3

Estimated Gross Benefits of Adopting PAYD Auto Insurance in the United States

Impact of PAYD		Social values	Benefits: U.S. total ($ billions)	Benefits: Per vehicle (dollars)
Reduce driving by 8 percent (222 billion miles)	Reduced Accidents			
	Individual insurance cost savings net of lost driving benefits	Varies by state	7.7	34
	External auto insurance cost savings	Varies by state	21.3	93
	Government accident cost savings	N/A	2.0	9
	Other accident cost savings[1]	N/A	3.2	14
	Reduced congestion	6 cents/mile	13.3	58
	Reduced local pollution	1.5 cents/mile	3.3	15
Reduce fuel consumption by 8 percent (11.2 billion gallons)	Reduced carbon emissions	$25 ton/$CO_2$ (22 cents/gallon)	2.5	11
	Reduced oil dependence	50 cents/gallon	5.6	25
Total gross benefits			**58.9**	**257**

Source: Authors' calculations

Notes: Savings in 2007 dollars. Individual and external insurance cost savings calculated based on state-by-state driving reductions estimated by authors. All other benefits based on nationwide 8 percent reduction in driving and fuel consumption from initial 2006 values for all light-duty vehicles.

1. Other accident cost savings include reduced accident-related traffic delay, medical costs accruing to accident victims and their private medical insurance companies, and lost wages and household productivity incurred by accident victims who are incapacitated or fatally injured.

17. The equivalent gasoline tax increase assumes an initial retail price of $2.73 per gallon, which was the national average for the first eleven months of 2007, the most up-to-date data at the time of this paper's data analysis. To achieve an 8 percent reduction in driving and with an initial gasoline price of $4-a-gallon, an increase of $1.45 in the gasoline tax would be required.

i. Individual auto insurance cost savings.

A switch from lump-sum to per-mile auto insurance premiums allows people to save money by driving less. As we have discussed, lump-sum insurance premiums lead to inefficiently high driving. For example, suppose driver Dan travels twelve thousand miles a year and is charged $1,200 a year in liability, collision, and uninsured motorist insurance premiums. Dan is implicitly charged 10 cents per mile for insurance. Because Dan pays the insurance premium up front and in a lump sum, though, he does not consider it in deciding how much to drive. He only considers the costs that depend directly on mileage, what economists call his marginal costs: fuel, vehicle maintenance, internal accident costs (the value he puts on his own life and limbs given a risk of injury), and the value of his time. He drives up to the point where the benefits he derives from each additional mile just equals these marginal costs. To be sure, as noted earlier he knows that if he drives more he is more likely to get into an accident or be cited for a moving violation, which would make his premiums go up next year. However, considering that the average driver only gets into an accident every twenty years, this is far from a direct incentive (Insurance Information Institute n.d.). If Dan faced per-mile insurance premiums, however, he would recognize that each additional mile actually costs him an additional 10 cents. Some of the miles he is driving would not be worth 10 extra cents to him. If he could save 10 cents by eliminating the miles he values at less than 10 cents he would be better off. PAYD allows this to happen, whereas lump-sum pricing does not.

Each driver's benefit from switching to PAYD equals his insurance cost savings net of the surplus he was enjoying from driving the miles he gives up. For example, if Dan valued one hundred of the miles he drove at only 4 cents a mile above his marginal cost, he would not drive them anymore if he were charged 10 more cents for them. By not driving them, he loses 4 cents in surplus but gains 10 cents in reduced insurance costs, so he is 6 cents per-mile-avoided better off than before. State-by-state estimates for these individual accident cost savings net of lost driving benefits are reported in Table 2. Nationally, we calculate the savings would total $7.7 billion a year (see appendix).

These savings could in theory go partly to insurance companies if the market is not immediately competitive (Edlin 2003). Knowing that per-mile premiums will make their customers better off by billions of dollars in aggregate, insurance companies initially may be able to extract some of that benefit as profit. If all the benefit went to insurance companies, they could make $34 per vehicle that switched to PAYD. Eventually, as the market became competitive, we would expect these savings to accrue instead to drivers. (As detailed in §5 (D), PAYD also eliminates the transfer from low-mileage to high-mileage drivers implicit in the current lump-sum pricing scheme. We calculate the average low-mileage driver will save $318 per vehicle from the elimination of this transfer. While this will be offset in aggregate by higher premiums charged to high-mileage drivers, a first-mover insurance company able to lure low-mileage drivers from other companies could in theory capture some of that $318 in savings itself.)

ii. External auto insurance cost savings.

Accident savings accrue to all other drivers and their insurance companies when any one driver forgoes a mile. Again, consider driver Dan. For each car with which Dan crosses paths when he drives one mile, there is a (small) probability that Dan's car and the other car might collide. If Dan does not drive that mile, that probability goes to zero.[18] So for every mile that Dan avoids driving, he reduces the accident risk of all other drivers on the same road at the same time. Dan does not consider this cost when he decides whether to drive, but when he reduces driving all other drivers are better off.

18. This is not to say the other cars no longer have any accident risk: they just have no risk of colliding with Dan.

One way to measure the accident externality is to calculate how much all other drivers' insurance costs rise when any one driver decides to drive another mile. Aaron Edlin and Pinar Karaca-Mandic (2006) use a panel data set on insurance premiums, insurance costs, traffic density, and control variables from 1987–95 to measure this relationship. They model the accident externality as a function of traffic density in each state. In states where traffic density is high, the probability of crossing paths with another driver is high, and thus so is the accident cost imposed on them. We use the relationship Edlin and Karaca-Mandic find to calculate the accident externality in each state (for details see appendix). Following those authors, we obtain data on total VMT and total lane miles in each state from *Highway Statistics*, published by the U.S. Department of Transportation (DOT 2006).

Our resulting estimates of the per-mile accident externality for each state are reported in Table 2. As we would expect, the accident externality is highest in the states with highest traffic density (measured in vehicles per lane-year, also reported in Table 2). In Hawaii, the most traffic dense state, the external accident cost is 53 cents a mile, more than five times the individual driver's per-mile premium. In New Jersey, the second-most traffic dense state, the external accident cost is 34.4 cents per mile, three and a half times the individual driver's per-mile premium. In most states, however, the external accident cost is smaller than the per-mile premium. In some states with very low traffic density, the external accident cost is even negative. This could be because, as driving increases, it causes other drivers to drive more slowly and thus reduces the frequency or severity of accidents. Such a scenario is more likely in extremely high-traffic-density situations, where more drivers plausibly might cause speeds to fall, not in the less-dense states for which we find negative external accident costs. More likely, the negative external cost numbers result because the particular model developed by Edlin and Karaca-Mandic (2006) is not designed for states with very low traffic densities. The model treats external accident costs as a quadratic function of density in a given state. In their results, the coefficient on density-squared is positive but the coefficient on density is negative and of greater magnitude. In states with very low traffic densities, the negative term dominates. None of the negative externality numbers for these states on the edges of the distribution are statistically significant (see appendix).

External accident cost savings from PAYD are reported in Table 2.[19] Nationally, we estimate the savings would total around $21 billion a year, which should be thought of as a conservative estimate for an 8 percent reduction in driving. We have assumed every driver in each state faces the same premium, but in reality per-mile insurance premiums would be adjusted by all the other normal risk factors. The drivers most likely to get into accidents would be charged the highest per-mile premiums. Hence the reduction in mileage will be concentrated among the most risky drivers, generating higher accident savings than a proportional mileage reduction across all drivers (Edlin 2003).

iii. Other external accident cost savings.

Traffic accidents have many social costs that are not covered by auto insurance and that do not accrue to those responsible for the accidents. These costs are thus additional external accident costs. One part of these costs are medical costs incurred by victims, paid for out of their own savings or through private insurance plans such as Blue Cross-Blue Shield, HMOs, commercial insurance policies, or worker's compensation. Another is lost wages and household productivity incurred by accident victims who are incapacitated or fatally injured. A third and major cost is the time delay incurred by drivers suffering in traffic caused by accidents (which is not captured in the figures measuring delay caused by high traffic volume discussed below). A widely cited report conducted by the National Highway Traffic Safety Ad-

19. In calculating external accident cost savings, we incorporate that external accident costs fall as mileage falls. We are grateful to Aaron Edlin and Pinar Karaca-Mandic for sharing the full results of their analysis and for confirming our results.

ministration (NHTSA 2002) estimated these costs together accounted for 15 percent of total social costs from accidents in 2000, amounting to $40.2 billion (updated to 2007 dollars). If we assume an 8 percent reduction in driving will lead to an 8 percent reduction in crashes and an 8 percent reduction in these costs, the social benefits would total $3.2 billion. This may be a conservative assumption, because there is theoretical and anecdotal evidence (which we have already discussed) to suggest accidents would fall more than proportionately with mileage. Conversely, reduced mileage could open up roads and increase driving speed, increasing the frequency or severity of crashes.

The other part of additional external accident costs are those that accrue to federal, state, and local governments. These include medical payments through Medicare and Medicaid, lost tax revenues from reduced productivity by incapacitated or fatally injured workers, and the cost of emergency services responding to crashes and cleaning up after crashes. The NHTSA (2002) study estimated that government costs accounted for 9 percent of total social costs of accidents in 2000, amounting to $25.3 billion (updated to 2007 dollars).[20] Making the same assumptions as above, an 8 percent reduction in these costs would save the government $2 billion, $1.4 billion of which would accrue to the federal government.

While the above figures account for the economic costs of lost workplace and household productivity from injuries and fatalities, there are obviously many other benefits to reducing the number of fatalities and injuries—and the impact of PAYD could be substantial. According to the Fatality Analysis Reporting System (FARS) of the NHTSA, in 2006 there were 1.4 fatalities per 100 million VMT in the United States. Using the same assumption as above, if fatalities dropped proportionally by 1.4 per 100 million vehicle miles avoided from PAYD, the reduction in driving of 222 billion miles would lead to 3,108 fewer fatalities a year. The estimates for avoided injuries are less precise. While the FARS database is an accurate count of fatalities on all public roads in the United States, there is no such comprehensive data source for injuries. The previously mentioned NHTSA report (2002) compiled data from various different sources and estimated an injury rate of 116 per 100 million VMT in 2000. The report found a decrease throughout the 1990s of on average 3.5 injuries per 100 million VMT a year. Assuming that trend continued into this decade, the rate would stand at ninety-five injuries per 100 million VMT in 2006. Based on this estimate, an 8 percent reduction in driving would lead to 210,900 fewer injuries.

iv. Reduced congestion.

Only two studies have been done that attempt to estimate the marginal external congestion cost for the United States. The FHWA (U.S.DOT 1997, 2000) provided an estimate of 5 cents per mile using speed-flow curves for certain rural and urban road classes and weighting these by their respective U.S. mileage shares. Fischer, Harrington, and Parry (2007) recently developed another estimate by using the results from a computational model of the metropolitan Washington, DC road network. Extrapolating over the seventy-five largest U.S. cities and including data on all driving in the U.S., they find an average marginal congestion cost of 6.5 cents per mile for driving on all U.S. roads. We follow Fischer and colleagues in combining both estimates and using 6 cents per mile as the parameter. An 8 percent reduction in VMT would thus yield a benefit of $13.3 billion in the form of reduced congestion. This is a highly simplified figure. External congestion costs are not the same for each mile driven. It varies by location and time of day. The above studies try to find the cost of the average mile in America, but this is inherently imprecise. Another assumption behind the $13.3 billion figure is that mileage reduction from PAYD is the same in more-congested as in less-congested areas of each

20. To complete the picture, the study found that 50 percent of social accident costs are covered by auto insurance, and that 26 percent are internalized by drivers who are responsible for crashes.

state. But it may be possible that wages are higher in more congested urban areas, which possibly would lead to lower driving price elasticities, and hence less reductions in urban areas. However, urban areas have more-extensive and more-reliable public transit alternatives to driving (CBO 2008), which pushes in the other direction.

v. Reduced local pollution.

Vehicles burning gasoline emit NO_X and HC into the air. NO_X and HC react in sunlight to form ozone, which is the main component of smog. Smog is especially problematic for senior citizens, children, and people with pulmonary conditions because it can inflame breathing passages and decrease lung capacity. Smog also increases the body's susceptibility to illness. In addition to ozone, NO_X and HC react to form particulate matter that can be small enough to reach lung tissue. A study by Laden, Schwartz, Speizer, and Dockery (2006) found a positive and statistically significant relationship between particulate matter concentrations and cardiovascular and lung cancer mortality in six American cities.

Most studies trying to quantify the social cost of NO_X and HC pollution from vehicles treat the damage as proportional to distance traveled because new passenger vehicles have been subject to grams-per-mile standards for NO_X and HC since the 1970 Clean Air Act (see Parry and Small 2005; Fischer et al. 2007). These standards ensure that virtually all vehicles, regardless of age or fuel economy, emit local pollutants at the same per-mile rate (Parry et al. 2007) We follow the recent study by Fischer and colleagues that estimated the cost specifically for the United States. That study finds an external local pollution cost of 1.5 cents per mile, which implies a $3.3 billion savings from an 8 percent reduction in mileage.

vi. Reduced CO_2 emissions.

PAYD will reduce fuel consumption by the same proportion that it reduces driving. From the NHTS data, we calculate that 99.7 percent of the fuel consumed by light-duty vehicles is gasoline, so we focus on gasoline in this section. Each gallon of gasoline contains 0.0024 tons of carbon (National Research Council 2002), which when burned becomes 0.0088 tons of CO_2. An 8 percent reduction in gasoline consumption by these types of vehicles (an 11.2 billion gallon reduction) would directly reduce emissions of CO_2 by 99 million tons (Table 4.)

Reducing consumption of one gallon of gasoline saves more than just the carbon in that gallon. Carbon is emitted all along the process of turning the oil in the ground into gasoline in a vehicle's tank. It is emitted in drilling, transporting, refining, and blending. A study by Bringkman, Wang, Weber, and Darlington (2005) sought to measure these total "well-to-wheels" emissions. Based on their results, we calculate that reducing consumption of gasoline by one gallon reduces total CO_2 emissions by 0.0112 tons, 27 percent more than the direct emissions reductions. By that count, reducing gasoline consumption by 8 percent reduces CO_2 emissions by 126 million tons, 2 percent of total U.S. CO_2 emissions in 2006 and 8.5 percent of all emissions from cars and trucks in 2006 (Table 4).

Estimates of the external social cost of CO_2 are notoriously varied. The Nobel Prize–winning Intergovernmental Panel on Climate Change (IPCC) recently surveyed one hundred estimates and found a range from $3 to $95 per ton (IPCC 2007). In a recent paper for The Hamilton Project, economist Gilbert Metcalf (2007) surveyed the literature on the social cost of carbon and proposed a CO_2 tax of $15 per ton that would quickly ramp up to and pass $25. In another Hamilton Project paper, economist Rob Stavins (2007) proposed a cap-and-trade system with an implied initial CO_2 cost between $18 and $41 per ton. Given the wide range of estimates, we use a central value of $25 per ton of CO_2. Based on that estimate, each gallon of gasoline saved yields a 22-cent benefit (using direct CO_2 emissions) for a total savings of $2.5 billion.

vii. Reduced oil dependence.

Reducing driving and fuel consumption by 8 per-

TABLE 4

CO_2 Emissions Reductions from PAYD

	Tons of CO_2	As a percent of total CO_2 emissions, 2006 (percent)	As a percent of CO_2 emissions from cars and trucks, 2006 (percent)
Direct CO_2 emission reductions	98,912,000	1.67	6.69
Well-to-wheel CO_2 emission reductions	125,888,000	2.12	8.51

Source: Authors' calculations.

cent among the vehicles we consider (7.4 percent among all vehicles on the road) would reduce U.S. oil consumption by about 4 percent. This reduced oil consumption has national and economic security benefits. Various studies have tried to quantify the specific economic costs of oil dependence. The economic costs are generally divided into three categories, and the estimates for each depend heavily on highly uncertain parameters. First, imperfect competition in the oil market implies the world price is inflated above its competitive level. To the extent that the United States has monopsony power—as a consumer of one-fourth of the world's daily oil supplies—domestic consumers over-consume because they ignore the impact they can have on world prices. Studies estimate the external cost from this monopsony component to be between 8 and 48 cents per gallon, depending on various assumptions (Leiby 2007; Newbury 2005). Second, market imperfections such as wage and price rigidities and producers' inability to rapidly adjust energy inputs decrease the economy's capacity to adjust to price shocks, leading to excessive underutilization of available resources and increasing aggregate economic costs during price spikes. While mechanisms to help businesses and households adjust more easily (such as oil futures markets and energy conservation measures) have proliferated in recent years, consumers and producers will only take protective actions against the risks that they expect to bear directly, failing to consider the impact of their decisions on wider disruption costs. Leiby estimates this cost at between 6 and 20 cents per gallon. Finally, some studies find that oil consumption leads to increased military expenditures in sensitive oil-producing areas. Analyzing only the Middle East, Delucchi and Murphy (2008) estimated the marginal gallon of gasoline consumption increases military expenditure by 3 to 15 cents. Aggregating the three components of marginal external costs of oil dependence leads to a range of 17 to 83 cents per gallon of gasoline.

None of these studies includes the arguably significant geopolitical costs of oil consumption:

- increasingly wealthy oil-supported authoritarian governments,
- the inability of U.S. foreign policy to deal with hostile states for fear of oil supply–related repercussions,
- the demise of freedoms in these countries (Friedman 2006),
- the increase in resentment toward U.S. military presence in the Middle East (tied to securing stable oil supplies), and
- the flow of oil funds to terrorist organizations.

These costs are widely recognized (see Council on Foreign Relations 2006; Bordoff, Deshpande, and Noel forthcoming) but are virtually impossible to measure in dollar terms. This would push us toward using the high range of the estimates for the economic costs of oil dependence as an estimate of the combined economic and national security costs. However, there is also reason to believe the high estimates of the economic costs are too high. Lower energy intensity, improved management of monetary policy, and greater flexibility in the economy have decreased the economy's vulnerability to oil shocks (Blanchard and Gali 2007; Nordhaus 2007). Conversely, at the time of this writing the current oil shock had pushed U.S. spending on oil as a percent of GDP up to its highest level in twenty-five years, and the economy is showing signs of significant strain. Given the large uncertainty about the external cost of oil consumption, we adopt an estimate of 50 cents per gallon, the mid-point in the 17 to 83 cent range of values for the economic portion of the external cost of oil dependence. At this rate, the oil demand reduction from PAYD saves $5.6 billion.

viii. Fuel taxes, road maintenance and roadway investment costs.

As driving falls, so will the cost of maintaining existing roads and building new roads to meet demand. We do not count savings on road maintenance in the social benefits, though, because we assume current fuel taxes roughly offset marginal maintenance and roadway investment costs of additional miles driven. In other words, we assume these user costs are already internalized by drivers.

This is a simplifying assumption, but it is not clear in what direction it biases our results. On the one hand, fuel tax and other user fee revenues have been steadily declining as a share of total road and highway spending. In 2006, user fees only covered 63 percent of the $147.6 billion that federal, state, and local governments raised to support road and highway programs (DOT 2006, Table HF-10). This would imply that the infrastructure costs imposed by drivers are not fully internalized by the fuel taxes they pay, and thus that reduced driving would have some additional social benefits. On the other hand, it is impossible to determine whether that spending reflects the true costs that users impose on the system. Without user fees such as tolls, VMT taxes, or congestion charges, no price signals are sent to planners indicating the efficient level or distribution of physical infrastructure spending (Deshpande and Elmendorf 2008). The minor social savings calculated by using current spending as an indicator of imposed infrastructure costs is dwarfed by the uncertainty about the true level of a driver's imposed costs, so we do not take a stand one way or the other.

ix. Total gross benefits.

If all light-duty vehicles switched to PAYD auto insurance, we estimate gross social benefits would total $58.9 bllion a year. The benefit per car would be $257, over seven times higher than the direct savings to insurance companies and their customers.

In addition, PAYD would have other social benefits that are harder to quantify. For example, PAYD would likely reduce the number of uninsured vehicles on the road. The current policy of lump-sum auto insurance premiums makes insurance very expensive for people who own cars but use them infrequently. Some of these motorists forgo auto insurance altogether, even in states that require it. Bringing down the cost of auto insurance for such drivers would encourage more of them to purchase insurance. In the calculations presented in this section, we implicitly assume such drivers do obtain insurance when PAYD becomes available. The calculations present benefits from reducing mileage and fuel consumption by 8 percent from *all* light-duty vehicles, not just those that were previously insured.

x. Estimated costs

Switching every vehicle to PAYD would come at a cost because insurers would need to monitor miles driven, but estimating this cost is difficult. We report in Table 1 that commercially available telematic devices cost between $50 and $170 up front and sometimes entail monthly or yearly data transmission costs as well. But conversations with insurance companies indicated the cost of these devices is falling quickly and that the price reported to us may be higher than the price for a bulk buyer such as a large insurance company. If PAYD became widely offered with telematic devices to record mileage, it is likely the costs of these devices would fall still faster. Further, as previously discussed PAYD does not necessarily require telematic devices. Simple odometer audits performed by accredited safety and emissions inspectors or others could provide verified mileage data at far lower costs than with telematic devices. Other PAYD models also exist that do not require high up-front costs; for example, Milemeter allows consumers to buy insurance online for a certain number of miles and requires them to monitor their own odometer miles and purchase additional insurance as needed in order to be covered.

Given this wide range of potential costs, we do not endeavor to predict what they would be. But even taking a high-end cost estimate, the benefits of PAYD remain substantial. For example, if we assume a monitoring cost of $40 per vehicle per year (which would be the cost if a telematic device were $100, consumers replaced them every five years, and it cost $20 per year for transmission of data to the insurance firm), the net benefits of PAYD would still be $50 billion per year.

C. Estimating the Distributional Impact of PAYD

Although Edlin (2003) and Parry (2005) estimated the national benefits from PAYD, we can find no previous study that endeavored to estimate impacts on a driver or household level. With the detailed data in the 2001 NHTS described above, we are able to begin answering the distributional question.

First, we calculate the major distributional impact from PAYD: the elimination of the subsidy from low-mileage to high-mileage drivers. To estimate this transfer we divide vehicles into risk classes. We group them by their state, by their registration in either urban or rural areas, and by their vehicle type (car, van, pickup truck, or SUV). We calculate the average mileage for a vehicle in each risk group. We then assume that vehicles driven less than the average for their risk group save insurance premiums equal to the product of the average per-mile premiums charged in their state and the difference between their annual mileage and the average mileage for their risk group. Under this calculation, the total insurance premium paid by all drivers in the risk group remains the same. There is simply a reallocation away from those who drive less to those who drive more and thus probably have more accidents.

Second, we measure the benefit to all drivers who can now save money on auto insurance by driving fewer miles. This calculation was described above and is explained in detail in the appendix. Even drivers who now lose from the elimination of the subsidy to high-mileage drivers save money by having the opportunity to lower their (now higher) premiums by driving less.

To get a clearer picture on a household level, we group the results of all vehicles in a household to determine how each household is affected. Because the NHTS data include information on household variables such as income, we are able to break down the impact by income group.

Of course, this gives only a rough idea of the true distributional impact of PAYD. As with the driving reduction benefit, our analysis is limited because we assume that all drivers in each state face the same per-mile premium, regardless of their risk class, and that that all drivers in each state initially purchased the same amount of insurance coverage. We do this because we only have insurance premium data by state. More significantly for the distributional analysis, however, is the limited way we are able to group drivers into different risk classes. We have only considered three of the many variables insurance companies price insurance on. We are limited for two reasons. First, we simply do not have data on some of the relevant variables, most notably accident history. This is a significant issue that biases our estimates upwards. As shown in Figure 2, we would expect low-mileage drivers to be more risky per mile. Many of the "winners" in our current analysis probably would be charged higher per-mile premiums as a result, while many of the "losers" would be charged lower per-mile premiums than we assume. This implies that the magnitude of predicted savings and losses are somewhat overstated. Another related issue is that some low-mileage drivers are already receiving some (minor) premium discounts from insurance companies who offer them, further biasing our estimated savings upwards. But since all current discounts are based on self-reported data, it is impossible to know if those receiving such discounts are actually low-mileage drivers, so the degree this impacts our results is unclear.

The second reason we are limited in grouping into risk class is that we quickly run into small sample problems. The NHTS includes many relevant variables that we know companies consider when evaluating a vehicle's risk exposure, such as information on the age and gender of all the vehicle's drivers as well as the make, model, and year of the vehicle itself. We cannot use this information because the three variables we do group by already divide the 41,672 vehicles into several hundred risk groups. Adding another variable into the mix leaves too many vehicles in the sample in a group by themselves. In proceeding with an imperfect grouping along a subsample of the relevant variables, we acknowledge the incompleteness of our data and the limitations of our analysis. We nevertheless believe the exercise leads to important observations.

D. Distributional Impacts of PAYD

Table 5 describes the broad results from the analysis described above, aggregating individual accident savings and the elimination of subsidies from low-mileage to high-mileage drivers. Assuming every vehicle switches to PAYD, almost two-thirds of all households save money, with the average savings for those households that save totaling $270 per vehicle, which is 28 percent of current average auto insurance payments (including comprehensive). The elimination of subsidies accounts for most of the distributional impact. Savings per vehicle from reduced mileage average only $18 per vehicle for households who save money, and only $48 per vehicle for households who would pay more in total. The elimination of subsidies, on the other hand, accounts for $252 of the savings for households who save money and $418 of the increased costs for households who would pay more. If we look at the vehicle instead of the household level, almost two-thirds (63.4 percent) of vehicles would have lower insurance premiums, with the average savings for those with lower premiums of $333 per vehicle ($15 from driving reductions and $318 from the elimination of the subsidies to high-mileage drivers). The savings for those who save (and losses for those who pay more) are greater at the vehicle level than at the household level because within each household there may be some vehicles driven more than average and some driven less than average.

The high proportion of drivers that would pay less under PAYD reflects the fact that a minority of high mileage drivers is responsible for a majority of driving *within* each risk class. Figure 5 shows that the top 20 percent of drivers are responsible for 45 percent of all miles driven. In other words, the average number of miles driven is higher than the median number of miles driven. Thus, PAYD results in a transfer from the minority of high-mileage drivers

TABLE 5

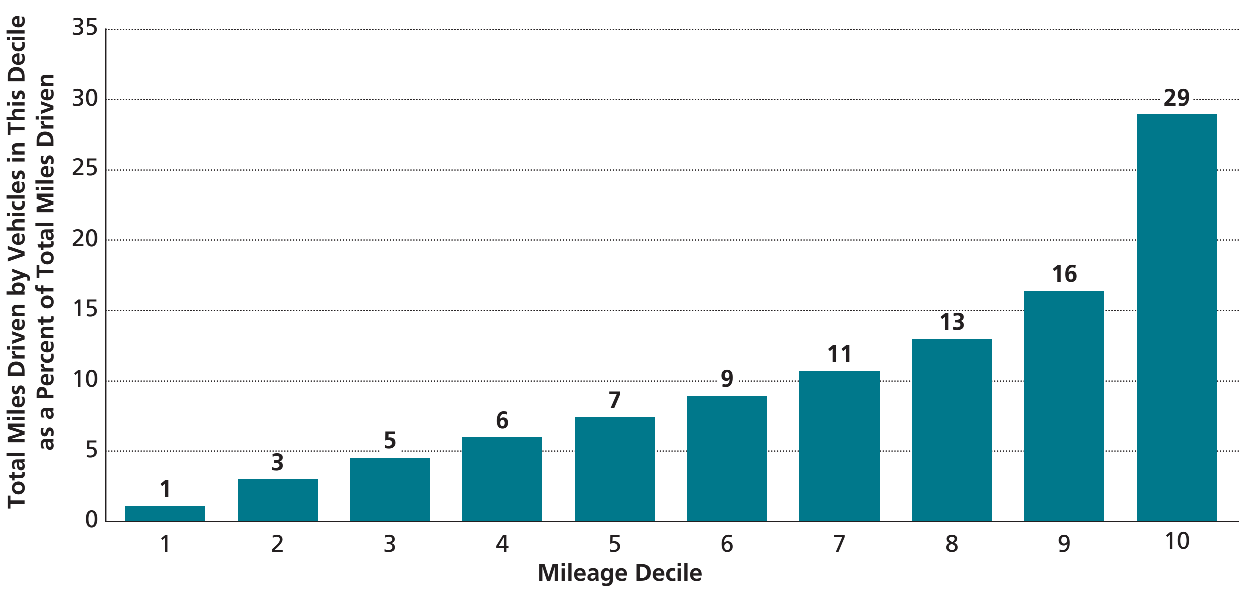
Insurance Savings from PAYD

	63.5 percent of households save money	36.5 percent of households pay more
Average change in insurance premium per household	–$496	$713
Average change in insurance premium per vehicle	–$270	$370
Change in premium per vehicle from elimination of transfer from low mileage to high mileage drivers	*–$252*	*$418*
Change in premium per vehicle from reduced mileage, net of lost driving benefits	*–$18*	*–$48*
Change in premium as a percent of annual insurance premium (including comprehensive coverage)	–28%	38%

Source: Authors' calculations.
Note: Numbers may not add up due to rounding.

FIGURE 5

Distribution of Driving, by Mileage Decile



Source: Authors' calculations based on data from the 2001 National Household Transportation Survey.

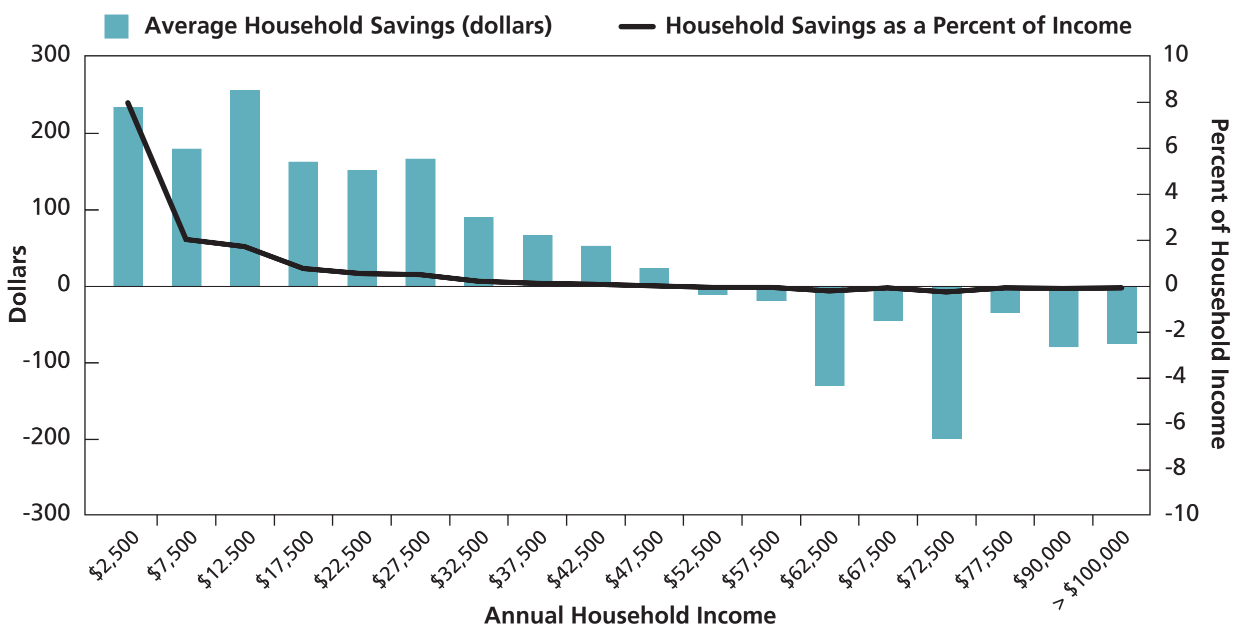
to the majority of low-mileage drivers. This transfer is fair because it eliminates the subsidy low-mileage drivers were paying to cover the accident costs for the high-mileage drivers in their risk class.

The very limited real-world experience with PAYD confirms these potential savings. In a pilot program in the U.K. administered by Norwich Union, a quarter of their customers saved 30 percent compared to what they would have paid under the standard Norwich Union Motor Insurance premium (Norwich Union n.d.).

Low-income families will especially benefit, on average. Our data show that they make up a disproportionately large fraction of the low-mileage drivers within any risk class. Figure 6 breaks down the accident cost and transfer savings by income group reported in the 2001 NHTS. As the figure shows, every household income group making less than $52,500 (in 2001) saves on average. This is especially significant because their savings make up a far greater proportion of their incomes, whereas the losses for the high-income groups are virtually insignificant (Figure 6). This should not be construed as implying that most high-income drivers are worse off. On the contrary, Figure 7 shows that a majority of drivers in each income group saves money with PAYD.

FIGURE 6

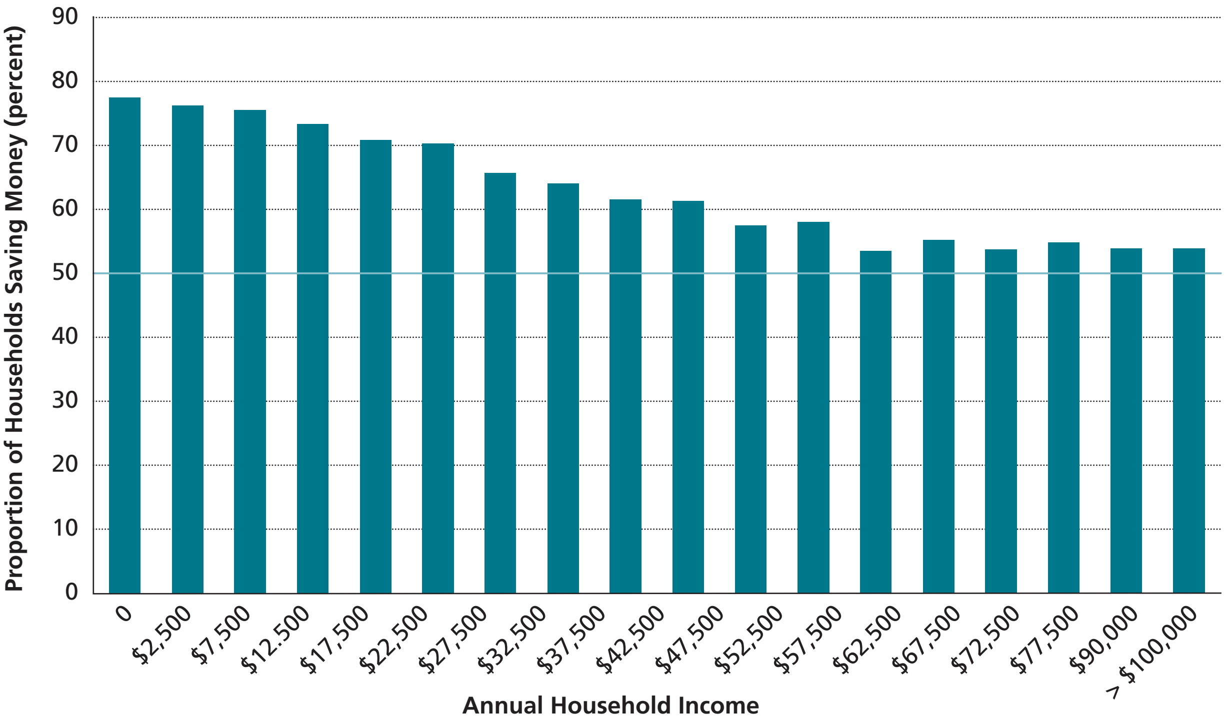
Estimated Household Savings from PAYD, by Annual Household Income



Note: Savings in 2007 dollars but household income groups in 2001 dollars. Savings are deflated to 2001 dollars to calculate percentage of 2001 income levels.
Source: Authors' calculations.

FIGURE 7

Proportion of Households Saving Money with PAYD, by Annual Household Income



Source: Authors' calculations.

In addition to benefiting specific demographic groups, PAYD can benefit all households by increasing the affordability of vehicles. Because car insurance is currently priced as a large fixed yearly cost (roughly one-fifth of the annual financial costs of owning an intermediate sized car [Litman 2007a]), some families simply cannot afford to own a car, which limits their mobility. Also, PAYD makes it cheaper for families to purchase a second or third car (although they have less incentive to do so than before because PAYD gives them the incentive to drive less). Currently, a family would pay significantly more in auto insurance for two cars than it would for one car, even if the total miles the family drove did not increase but was spread over two cars. PAYD might thus encourage the purchase of a small, fuel-efficient second car in addition to a necessary larger car that can accommodate the whole family (and should thus be an attractive policy reform to the car manufacturers).

Others have suggested that PAYD would disproportionately help female drivers because women tend to drive less than men (Butler 1996). While we also find that a slightly greater proportion of women than men benefit from PAYD, this effect is not significant in our model. This is primarily because we have analyzed vehicles rather than drivers. When analyzing our data at the driver level, we find the same distribution as in previous studies, namely that the average male driver drives significantly more miles (63 percent more) than the average female driver (Table 6). However, as Butler points out, vehicles, not drivers, are insured. The relevant comparison from an insurance perspective then is to compare vehicles with women as the primary driver to vehicles with men as the primary driver. While such a comparison was not possible with the data available to the earlier studies, we were able to analyze this question. And on this score, we find a much smaller difference. Vehicles with male pri-

TABLE 6

Distribution of Driving, by Driver, Vehicle, and Gender

	Distribution of Driving by Driver			Distribution of Driving by Vehicle		
	All drivers	Males	Females	All Vehicles	Vehicles with Male Primary Drivers	Vehicles with Female Primary Drivers
Mean mileage	13,968	17,049	10,435	12,465	12,903	12,007
Median mileage	10,000	12,000	10,000	10,245	10,415	10,092

Source: Authors' calculations based on data from the 2001 National Household Transportation Survey.

mary drivers are driven only 7 percent more than vehicles with female primary drivers (Table 6). This explains why our results show similar proportions of men and women drivers benefit from PAYD.

E. Who Is Harmed?

Unless PAYD is mandated for all drivers, high-mileage drivers would not initially sign up because they would lose money by doing so. As the per-year insurance pool becomes limited to high-mileage drivers, average annual accident costs per driver will increase. This will lead to higher per-year premiums on high-mileage drivers, in effect a sort of back door mileage charge. We predict this will push ever more (and eventually all) high-mileage drivers into per-mile premiums. Either way, high-mileage drivers will pay more each year under our proposed reforms. This is only fair: high-mileage drivers get into more accidents (and impose greater external costs on the rest of society as well).

Still, policymakers may rightly be concerned about the impacts of a switch to PAYD on low-income drivers. Although most end up better off on average, there are undoubtedly many low-income drivers who drive more than the average and will thus end up worse off under PAYD. Given that the purpose of PAYD is to make drivers bear more of the insurance cost they impose, it is inevitable that some drivers, across the income distribution, will pay more in auto insurance. Indeed, it is that marginal cost of driving that provides the incentive to drive less. Concerns about the impact of such a policy on low-income people should, like concern for low-income people and rising inequality more broadly, be addressed through measures such as progressive tax reform (Furman, Summers, Bordoff 2007).

Another concern is that those who live in rural areas and drive many more miles will be adversely affected, but this concern is unfounded. That is because PAYD premiums will vary depending on other risk factors, and geography is one of the largest factors. Current insurance schemes are tailored down to the zip code. People that drive their cars in busy cities get in more accidents, and consequently pay more each year. People in rural areas driving on empty roads get in fewer accidents, and pay less each year. PAYD would keep the same distinction. We calculate that drivers in New Jersey would pay on average 9.7 cents per mile while drivers in Nebraska, North Dakota, and South Dakota would pay only 4.6 cents per mile. Since geography is a key risk factor, those in rural areas where people drive more will not be unfairly impacted because their premiums will be determined relative to how many miles the average driver in their areas drives. Table 7 shows almost two-thirds of household in both urban and rural households save money with PAYD.

TABLE 7

Households with Light-Duty Vehicles Saving Money with PAYD

	Percent who save
Urban households	63.7
Rural households	62.9

Source: Authors' calculations.

6. Why PAYD Is Preferable to Various Alternative Insurance Models

Recognizing the fundamental flaw that the pricing of auto insurance does not bring home to the driver the cost of the marginal mile driven, others have proposed variants of PAYD. For many years, the most discussed alternative to the current all-you-can-drive insurance system has been Pay-at-the-Pump (PATP). Under PATP, motorists would pay for their insurance as they buy fuel for their vehicles through a surcharge on fuel price, plus additional charges for high-risk drivers. Remarkably, the first published reference to PATP came in an address given in 1925 by Henry Swift Ives before the Safety Committee of the Cincinnati Automobile Club, revealing that people started to question the justification for charging for auto insurance on a lump-sum basis when cars were first starting to appear en masse on America's roads. Later, Daniel Patrick Moynihan proposed the idea in an article in the *New York Times Magazine* in 1967 ("Next: A New Auto Insurance Policy." *The New York Times*, August 27.)

Though people often conflate PATP and PAYD, PATP was motivated not by problems with the way auto insurance was priced, but rather with the inefficiency of the auto insurance system itself. PATP was thus primarily a tort reform proposal. Under one common variant of PATP, drivers would pay an additional charge per gallon of gasoline (which would be the largest source of funds). Drivers also would pay additional charges based on driving record and a vehicle ownership charge that would vary based on the vehicle's safety record (Sugarman 1994). PATP was thus one of the first no-fault auto insurance proposals. It would have replaced the lawsuit system of tort liability for bodily injury. Drivers would no longer have needed to purchase insurance covering bodily injury or liability insurance. Rather, the system, similar to worker's compensation, would have provided compensation to motor vehicle accident victims, based on a schedule of benefits.

By raising the cost of gasoline, PATP also would have created an incentive for people to reduce driving. However, PATP is inferior to PAYD in two key respects. First, most PATP proposals, such as Sugarman's Vehicle Injury Plan in California (1994), would have priced for accident risk much less precisely than traditional risk-based individual premiums. Indeed, some proposals did not vary the charges based on driver characteristics such as driving record. Second, because PATP insurance is tied to the amount of fuel used rather than the number of miles driven, much of the response comes from improvements in fuel economy rather than reduced driving, thereby providing far less benefit than PAYD toward reducing congestion and accidents (although this would provide larger benefits from reducing the less costly fuel-related externalities). Conversely, PATP may be better than PAYD in ensuring all drivers have insurance coverage, since you need to fill up to drive (electric cars aside).

A corresponding notion to adding the price of insurance to the cost of gasoline was advanced forty years ago by Vickrey (1968): adding the price of insurance to the cost of tires. Even Vickrey observed such a scheme was likely unworkable. For one thing, it would create an incentive for people to drive on bald tires, though he suggested that could be addressed by offering people a partial refund when they replace their old tires. The most serious defect he saw, though, was that the idea would not permit adequate geographical variation in the rates: there would be no way of preventing tires purchased in a rural low-risk area being used predominantly in a congested high-risk area.

7. Questions and Concerns

Several objections to PAYD may be raised, which are addressed below. But perhaps one way to address them all in a general way is to pose a hypothetical question and ask how people would likely react in the reverse scenario. Suppose that decades ago the technology existed to permit easy and low-cost odometer monitoring and a system developed whereby drivers were charged per mile traveled for auto insurance—which, as Vickrey (1968) observed forty years ago, makes more conceptual sense and may well have developed but for odometer fraud concerns. Imagine now that a legislator proposed to require insurance firms to abandon that system and charge all cars a lump sum each year for insurance regardless of how much a car's owner drives. What would the likely reaction be? It seems quite likely that the proposed system would be viewed as massively unfair to those who drive less than average and a much less precise way of charging people for use of insurance. Because higher income people tend to drive more, there would likely be allegations that legislators were helping those who were already well off at the expense of everyone else. It would be seen as harmful to a driver who owns several cars (and, incidentally, would thus be opposed vigorously by the auto manufacturers as a potential deterrent against the purchase of second and third cars). Although people tend to see the flaws with proposed reforms more than with those of the status quo, viewing the question through such a reverse hypothetical suggests strongly that the potential downsides of the status quo vastly outweigh those of PAYD. With that abstract conceptualization of the question, we address specific objections.

Is it fair to charge per mile given that someone who drives four times as much is only twice as likely to have an accident?

We noted earlier that the relationship between VMT and accidents is not proportional. One may ask, therefore, whether it is fair to charge a driver who drives twenty thousand miles four times as much as one who drives five thousand miles, even though the former is only twice as likely to be in an accident as the latter. First, the former will not be charged four times as much with per-mile premiums because the premiums are still risk adjusted. The premium will account for various other factors, such as driver age or experience, so that a lower risk driver will pay less per mile than a higher risk driver. Since per-mile crash rates differ significantly between motorists, it would indeed be unfair to use per-mile charges alone instead of other risk factors, but actuarial accuracy is increased when per-mile premiums are based on other rating factors.

Second, as already discussed, it is incorrect to suggest that because a comparison across different vehicles does not yield a proportional relationship, the risk of any individual vehicle being involved in an accident also does not. The driver who drives twenty thousand miles and the driver who drives five thousand miles are, on average, not equally good drivers, which is why the high-mileage driver is not four times as likely to have an accident—though she is still more likely. But for any individual twenty-thousand-mile good driver, her risk of having an accident does decline by 10 percent if she drives 10 percent fewer miles, unless the miles she forgoes are somehow lower-risk than the average mile she drives.

Will people actually choose PAYD over normal insurance premiums?

Almost two-thirds of American drivers will have a clear financial incentive to switch over to PAYD because they drive less than average. Under the current system, most drivers overpay compared to the accident and insurance costs they actually cause. Under PAYD, these drivers will be paying less. Some drivers may be hesitant if their miles vary widely from year to year and they are not sure whether they will save money by switching, but evidence shows most people prefer fees closely tied to usage rather than lump-sum premiums. In a survey commissioned by Norwich Union, the largest insurance group in the United Kingdom, nine out of ten people say they would prefer their auto insurance to reflect the usage of their car and the type of journeys they make (Litman 2007a). More than 50 percent favored "pay as you go" systems similar to what is offered by gas and electricity suppliers—precisely what PAYD offers. In a Minnesota study, 25 percent of respondents said they would definitely be interested in PAYD (Cambridge Systematics, 2006). According to Progressive, 34 percent of its customers in Michigan, Minnesota, and Oregon who signed up via telephone or the internet have been choosing their usage-based programs since 2004 (M. P. McQueen, "How Technology Can Help Trim Auto Insurance," *Wall Street Journal*, June 26, 2008). Based on the positive response to its TripSense Program, Progressive recently announced a national rollout of a usage-based insurance program. According to GMAC, enrollment in its Low-Mileage Discount Program with OnStar has tripled in the last year (ibid.).

Will mileage-monitoring systems raise privacy concerns?

Odometer readings are already widely publicly available. They are collected during vehicle servicing, vehicle sales, and crash investigations. Many are even sold by private companies such as CARFAX to used vehicle purchasers and insurance companies. The odometer auditing proposed in this paper simply standardizes and requires the collection of this information.

Electronic monitoring technologies, though, have the potential to go beyond simple mileage measurements by recording when and where a vehicle has been driven. There are four responses to this potential privacy problem. First, PAYD will always remain optional. If people prefer yearly premiums—because they do not want to share private information or for any other reason—they should still be able to get them, although adverse selection will make that a costlier option over time. Second, some people already have technologies that record all of this private information (such as OnStar) without any problem. Third, several of the technology options we have reviewed in this paper can be used to record total mileage only instead of capturing other personal driving data. Fourth, individuals are increasingly willing to share private information with companies if they can derive some benefit from doing so. For example, people type ever-more-revealing questions into Google's search engine, questions it uses to more-effectively target advertising, in exchange for quick and efficient access to information. Now people are even signing up to cell phone services that allow others to know their exact locations at any time (Amol Sharma and Jessica E. Vascellaro, "Phones Will Soon Tell Where You Are," *Wall Street Journal*, March 28, 2008). Indeed, Progressive has confirmed that in surveys of its customers more than half say they would be willing to allow Progressive to monitor their driving behavior in exchange for lower premiums; the response was even higher among low-mileage drivers who would benefit.[21]

Will PAYD actually reduce driving?

Americans pay an average of 6.6 cents in collision and liability insurance premiums for every mile they drive. Considering the average noncommercial vehicle gets about twenty miles per gallon in fuel economy, having drivers pay their insurance cost per mile rather than per year would give car owners the same incentive to drive less as adding $1.32 to the price of gasoline.[22] While recent expe-

21. Interview with authors. Progressive has not made its survey data available to the public.
22. This is consistent with our earlier claim that it would take a 99-cent increase in the gasoline tax to induce an 8 percent reduction in driving. Higher gas prices lead people who own cars to reduce driving and discourages potential buyers from buying a car (Parry 2005). Pricing auto insurance per mile driven, by contrast, only induces the former behavioral change (and may induce the opposite of the later change if people buy more cars because they can now afford insurance on cars driven few miles). Thus, it takes a higher per-mile premium per gallon than it takes tax per gallon to achieve the same reduction in driving.

rience with a more-than-doubling of gasoline prices since January 2003 confirms that consumption is relatively inelastic in the short run, driving behavior and fuel consumption is starting to change. Long-term evidence shows that consumers will turn these modest short-term behavioral changes into significant decreases in gasoline demand in the long run if gas prices remain at their current levels (Congressional Budget Office [CBO] 2008). At current prices, even the short-run response has been notable. The FHWA reported that total VMT fell 4.3 percent in March 2008 compared to March 2007, the first time March travel has fallen from the previous year since 1979 and the largest yearly drop from any month in FHWA history (DOT 2008). Whereas gasoline price changes are often perceived to be temporary, a switch to PAYD would give consumers a permanent, long-term incentive to change their driving habits.

Has PAYD ever worked anywhere else?

PAYD is being implemented successfully in a number of other countries (Litman 2007a). In Israel, 15 percent of all vehicles (two hundred thousand of them) run with PAYD insurance offered by Aryeh Insurance. Miles are recorded by small wireless transmitters in vehicles and received at fuel pumps. Polis Direct in the Netherlands has been offering its Kilometre Policy since 2004. Under this policy, participants pay an advance premium—90 percent of current prices—and can receive rebates of up to 50 percent off their premium for lower mileage. Mileage data are collected in annual vehicle inspections. Other countries with limited PAYD pilot programs include Canada (where Aviva Canada offers it in Ontario), Japan (offered by Aioi), and South Africa. Norwich Union in the United Kingdom has a pilot program, though it was recently paused.

Will PAYD disproportionately hurt truckers and bus drivers?

We assume that PAYD will not be offered to bus and truck drivers. They will thus not be impacted either way. Insurers must already have a much better idea how much such vehicles are driven and thus must develop premium programs tailored to them. Even if they did adopt a form of PAYD, per-mile premiums do not increase aggregate insurance costs for any risk class as a whole (and to the degree that it reduces driving, it reduces insurance costs for all risk classes). Rather, PAYD simply reallocates the burden of insurance costs within each risk category to those vehicles responsible for a greater proportion of the accident cost burden. The same would apply to buses and trucks if they were to adopt per-mile premiums: as a whole, they would be no worse off, but those who drove the most would pay more while those who drove less than average would pay less. Since the variance in miles among these groups is probably quite small, and certainly much smaller than among the vehicles we analyzed, the redistributional impact of PAYD also likely would be quite small.

Is PAYD the optimal insurance pricing scheme?

While adding mileage to the rating mix will increase efficiency and equity in the auto insurance market, even more can be done to price auto insurance more accurately and efficiently. Optimal premiums would incorporate other factors that contribute to accident risk, such as speed, time of day, and aggressiveness. Progressive is pursuing just such an approach. More sophisticated pricing schemes could lead to even greater social benefits than we have calculated. For example, telematic devices might detect aggressive braking patterns. If higher premiums for this activity cause drivers to drive more evenly, this could reduce congestion, fuel consumption, and pollution even if mileage remains constant. The EPA, for example, estimates that aggressive driving could lower gas mileage by 33 percent at highway speeds (U.S. Department of Energy, 2008).

To maximize impact on driving behavior, such information about driving behavior should be communicated in real time to drivers. Consider the efforts of Southern California Edison to encourage its consumers to conserve energy. While attempts to notify people by e-mail or text message about their energy use had little effect, people reduced energy use in peak periods by 40 percent when they were given an Ambient Orb, a little ball that glows red when a customer is using a large amount of energy, but green when energy use is modest (Thaler and Sunstein 2008). One can envision a similar indicator on the dashboards of cars that glows red when people are driving too fast, braking too hard, or driving aggressively, but green when they are driving more safely.[23]

Is PAYD the most efficient way to reduce driving-related externalities?

The purpose of PAYD is not to reduce driving externalities, but rather to correct a failure with the way that auto insurance is priced today and the inefficient and inequitable consequences of that pricing structure. While this failure is an important problem, what makes PAYD such an attractive policy is that by addressing it PAYD also would help reduce a range of driving-related externalities by creating an incentive at the margin for people to reduce their VMT.

That PAYD reduces driving-related externalities, however, does not mean that these externalities should not be priced to make drivers bear the full social costs of their driving. In a Hamilton Project paper, for example, economist David Lewis (2008) proposed a congestion fee, showing social benefits could exceed $10 billion a year. Global pollution costs from CO_2 emissions do not vary uniformly with mileage; large gains can come from increased fuel efficiency and the substitution of gasoline for renewable alternatives. The most efficient approach is a carbon pricing mechanism that creates an incentive to use less carbon, whether that takes the form of a carbon tax (Metcalf 2007) or a cap-and-trade system (Stavins 2007). The external costs of oil security vary with total consumption, not driving or even quantity of oil imported (Furman et al. 2007). The current system of gasoline taxes are the most efficient way of tackling this externality (as long as they apply only to oil, and not to renewable additives that can be mixed in with oil) (Bordoff, Deshpande and Noel, forthcoming). Harvard economist Greg Mankiw has proposed a $1 increase in the gas tax partly to reflect the cost of oil dependence ("The Pigou Club Manifesto." *The Wall Street Journal*. October 20, 2006), while his colleague Martin Feldstein has proposed a system of tradable gasoline rights as a way of reducing oil consumption and increasing national security ("Tradeable Gasoline Rights." *The Wall Street Journal*. June 5, 2006).

PAYD is not the answer to all driving-related externalities. The optimal strategy for dealing with the diverse driving-related social costs is a set of optimized user fees specifically calibrated to capture each externality, i.e., a combination of PAYD and the measures described above. Indeed, if monitoring for PAYD is done using mileage recording and transmitting technology inserted in vehicles, PAYD could pave the way for full network pricing that could piggyback on the PAYD technology. Yet all these additional proposals raise the cost of driving in the aggregate and thus are likely to provoke significant political opposition, particularly in a climate of rising gasoline prices. The promise of PAYD is that it can achieve some of the benefits of these user fees by creating incentives to reduce driving without raising the cost of driving in the aggregate, and indeed lowering it for the majority of drivers.

23. We thank Jeff Kling for suggesting that orbs be put in cars. We note that Thaler and Sunstein (2008) suggested the behavioral response could be even stronger if it "made annoying sounds, such as cuts from ABBA's Gold: Greatest Hits," but because tastes differ and their suggestion would actually encourage us to drive *more* dangerously, we decline to adopt their suggestion that audio be incorporated into the orb.

8. Conclusion

As record-high gas prices squeeze American households, PAYD could offset some of that pain by reducing the costs of driving for two-thirds of households. It is also more equitable, because low-income families would benefit disproportionately from lower insurance costs. At the same time, as our nation struggles with such challenges as oil dependence and climate change, PAYD would create incentives to reduce driving, thus helping to address these and other driving-related harms. In short, PAYD represents a win-win policy. What is good for drivers, in this case, is also good for society.

Appendix

A. Driving Response From per-Mile Premiums

We follow Parry (2005) who uses the literature on driving responses to fuel price changes to estimate the impact of per-mile premiums. We assume a constant elasticity demand function, where drivers respond to a switch from lump-sum to per-mile premiums by decreasing mileage from each vehicle as follows:

$$M_1 = M_0 + \beta_M \beta_m \eta_{FF} M_0 \frac{P_I}{P_F},$$

where M_0 and M_1 are initial and final miles traveled, respectively; $\eta_{FF} < 0$ is the gasoline demand elasticity in the long run; $ß_M$ is the fraction of reduced gasoline demand that comes from reduced vehicle miles rather than increased fuel efficiency; $ß_M$ is the fraction of reduced VMT that comes from reduced miles per vehicle rather than reduced vehicle demand; and P_I and P_F are the per-mile insurance and fuel costs, respectively. The ratio $\frac{P_I}{P_F}$ can be thought of as the proportionate increase in marginal fuel plus insurance cost from a starting point with an initial marginal insurance cost of zero. We exclude the portion of VMT reductions that traditionally come from decreased vehicle demand when fuel prices rise because the PAYD reform does not increase the cost of driving in aggregate the same way that fuel price increases do. Rather, it simply switches what was once a fixed cost of owning a car to a variable cost.

Parry (2005) reviews the literature and assigns a value of –0.55 for the long-run gasoline demand elasticity, 0.4 for the portion due to reductions in mileage, and 0.67 for the portion due to miles per vehicle. This model implies that per-mile insurance premiums as high as a vehicle's per-mile fuel costs would reduce that vehicle's mileage by 15 percent.

B. Individual Accident Cost Savings

The private benefit from reducing mileage as premiums are switched from lump sum to per mile is the total premium saved net of the consumer surplus lost. Given the linear driving demand assumed above,

Individual savings

$$= (M_0 - M_1)P_I - 0.5(M_0 - M_1)P_I$$

We report statewide savings in Table 2. Note that this assumes the driver was originally paying $M_0 P_1$ in lump-sum insurance premiums (i.e., the per-mile premium that driver faces is equivalent to his current lump-sum premium divided by his annual mileage). Of course part of the impact of PAYD is that many people would pay a different rate even if they did not reduce mileage. This is the elimination of the implicit subsidy from low-mileage to high-mileage drivers under the current system. The elimination of the subsidy is a transfer and thus is not counted in the social benefit analysis, but is considered in the distributional impact.

C. External Accident Cost Savings

Aaron Edlin and Pinar Karaca-Mandic (2006) estimate an equation that treats per-mile insurer costs as a quadratic function of traffic density:

$$r = c_1 + c_2 D + c_3 D^2$$

where r is the insurance cost for one driver driving one mile, and D is the traffic density in that state in any given year. Traffic density is a function of total VMT (M) and total lane miles in that state (L):

$$D \equiv \frac{M}{L}.$$

Edlin and Karaca-Mandic (2006) explain that density can be understood as the number of vehicles crossing a given point on a typical lane of road over a one-year period. In this model, any extra mile driven increases the per-mile insurance cost for each other mile driven that year. The total external accident cost can then be calculated as:

external marginal cost per mile of driving

$$= (M-1)\left(\frac{dr}{dM}\right)$$

$$= (M-1)\left(\frac{c_2}{L} + 2c_3\frac{M}{L^2}\right)$$

$$\approx c_2 D + 2c_3 D^2$$

for large *M*. This is the same result as Equation (4) in Edlin and Karaca-Mandic (2006) but with the coefficients having different meanings.

We calculate the accident externality for each state using 2006 values for VMT and lane miles from the FHWA's *Highway Statistics* (DOT 2006), using the relevant values for coefficients c_2 and c_3 that Edlin and Karaca-Mandic (2006, Table 3 column 10) estimate. The results, updated to 2007 dollars, are reported in Table 8.[24]

To calculate the external accident cost savings from PAYD driving reductions, we integrate the external accident cost over the aggregate mileage reduction in each state:

External accident cost savings from driving reductions

$$= \int_{M^1}^{M^0} c_2\frac{M}{L} + 2c_3\left(\frac{M}{L}\right)^2 dM$$

The results are reported in Table 8.

24. We are grateful to Aaron Edlin and Pinar Karaca-Mandic for sharing the full results of their analysis and for confirming our results.

TABLE 8

External Insured Accident Cost Savings from PAYD

	State or Division	External accident cost (cents)	Standard error	Total vehicle mileage from all vehicles, 2006 (millions)	Estimated new mileage with PAYD, 2006 (millions)	Reduction in external accident cost from driving reduction, (millions of dollars)
	Alabama	1	2.6	60,414	56,763	29.7
	Alaska	-0.8	1.4	4,967	4,474	-4
	Arizona	6.5	4.9	62,468	57,647	277.2
	Arkansas	-0.8	1.4	33,007	31,065	-15.7
	California	31.1	14.2	327,478	303,386	6,843.60
	Colorado	0.3	2.3	48,641	44,421	5.7
	Connecticut	18.7	9.5	31,743	28,838	482
	Florida	23	11.2	203,741	184,696	3,889.40
	Georgia	5.6	4.5	113,532	105,257	410.7
	Hawaii	52.9	22.5	10,182	9,098	506
	Illinois	2.6	3.3	106,869	99,786	161
	Indiana	2.3	3.2	71,215	66,825	90.2
	Iowa	-0.9	1.2	31,355	29,667	-14.8
	Kansas	-0.9	0.9	30,215	28,586	-14
	Kentucky	0.8	2.5	47,742	44,631	19.9
	Louisiana	2.3	3.2	45,417	41,619	71.3
	Maryland	28	13.1	56,302	52,047	1,085.70
	Massachusetts	20.6	10.2	55,136	49,694	986.1
	Michigan	3.9	3.8	104,184	97,047	242.9
	Minnesota	-0.5	1.8	56,518	52,786	-19.5
	Mississippi	0.4	2.3	41,498	39,044	5.5
	Missouri	0.3	2.2	68,834	64,612	5.4
	New Jersey	34.4	15.5	75,371	66,039	2,759.10
	New York	11.8	6.9	141,348	126,456	1,510.90
	North Carolina	6	4.7	101,515	95,635	322.8
	Ohio	4.2	4	111,247	103,908	277.6
	Oklahoma	-0.5	1.8	48,689	45,722	-15.4
	Oregon	0.3	2.3	35,483	32,961	4.8
	Pennsylvania	4.6	4.1	108,278	99,705	343.6
	South Carolina	2.4	3.2	50,199	46,881	69.6
	Tennessee	2.6	3.3	70,596	66,044	102.8
	Texas	2.6	3.3	238,256	222,078	361.6
	Utah	0.6	2.4	25,964	24,011	8.8
	Virginia	8.2	5.5	81,095	75,679	403.5
	Washington	1.5	2.8	56,517	52,225	52.7
	Wisconsin	0.1	2.1	59,398	56,294	-0.3
Division 1: New England	New Hampshire	4.4	4	13,614		
	Maine	1.5	2.8	15,044		
	Rhode Island	12.6	7.2	8,300		
	Vermont	0.3	2.2	7,832		
	These Division 1 states together	2.6	3.3	44,790	41,891	65.7
Division 4: West North Central	Nebraska	-0.9	0.9	19,415		
	North Dakota	-0.5	0.4	7,890		
	South Dakota	-0.6	0.5	9,168		
	These Division 4 states together	-0.7	0.6	36,473	34,779	-11.8
Division 5: South Atlantic	Delaware	19	9.6	9,442		
	D.C.	46.8	20.2	3,623		
	West Virginia	0.5	2.3	20,885		
	These Division 5 states together	2.5	3.3	33,950	31,280	57.2
Division 8: Mountain	Idaho	-0.8	1.3	15,198		
	Montana	-0.8	0.7	11,265		
	Nevada	1.1	2.7	21,824		
	New Mexico	-0.6	1.6	25,787		
	Wyoming	-0.8	1.4	9,415		
	These Division 8 states together	-0.8	1.4	83,489	77,103	-51.7
	U.S. Total	**2.4**	**3.2**	**3,014,116**	**2,791,359**	**21,306**

Note: Driving reduction from PAYD only occurs for light-duty vehicles. Thus, the inferred total driving reduction from this table is slightly lower than the percent driving reduction reported in the main text.
Source: Authors' calculations.

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